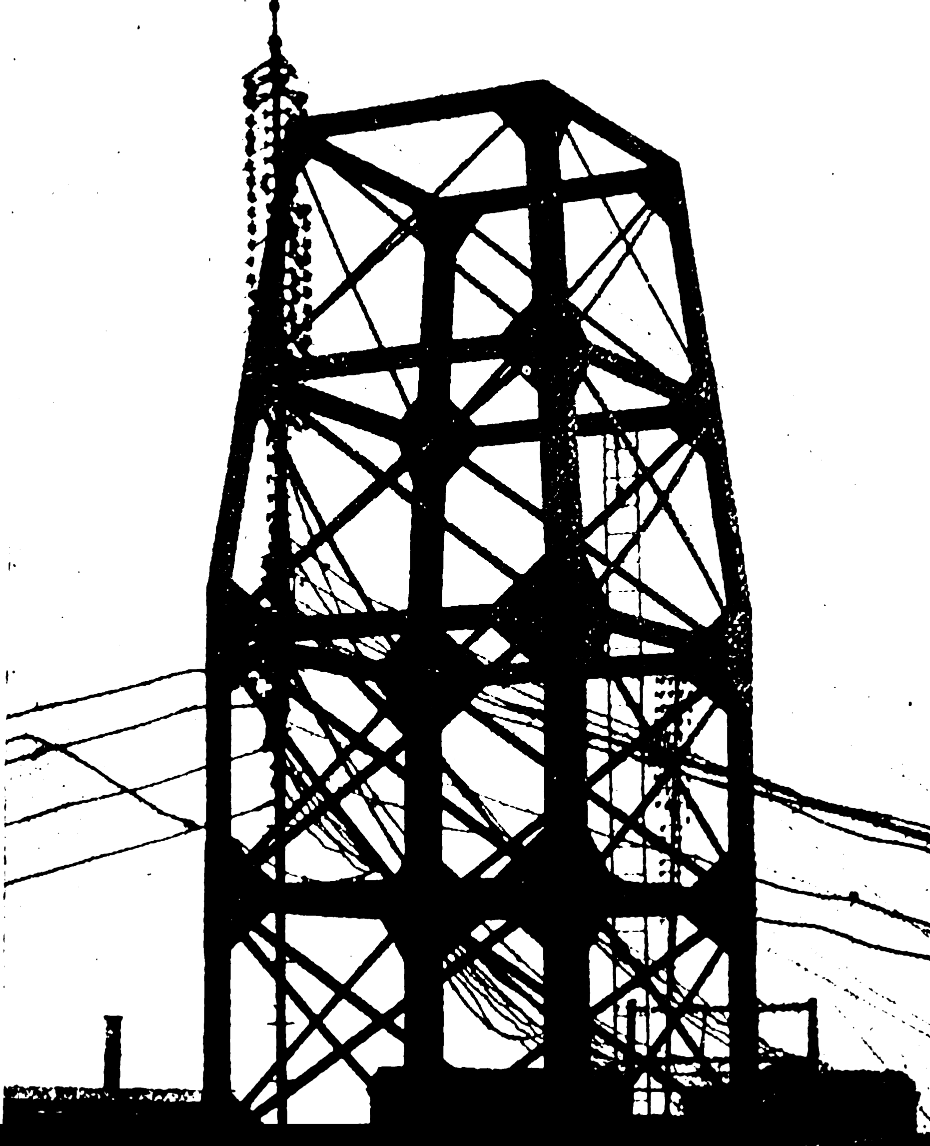

The telephone

Sir William Henry Preece, Julius Maier

PREFACE.

THE task which we have set ourselves in the present book of giving a detailed and reliable account of the present state of Telephony has been no easy one; since it was a question how, on the one hand, to describe a number of installations and apparatus which had not yet found their way into publicity, and on the other hand, to select from many proposed systems and arrangements those only which had been found practically useful.

If we have at all succeeded in accomplishing this task, we owe it in a great measure to the readiness with which we have been met by the different telephone administrations and by the inventors of telephone apparatus themselves, and we seize this opportunity of tendering to the respective gentlemen our best thanks for the original contributions with which they have supplied us for the purposes of this book.

We have paid little heed to priority, and have not attempted to regard patent rights or national prejudices. We have rather endeavoured to explain each point by selecting the best system in use, regardless of date or of country.

It will be found that we have briefly detailed the principles of sound and speech and the laws of induction, to which the telephone owes its birth and upon which is based its rapid growth to maturity.

We have but lightly touched on the historical side of the question, and have preferred to proceed at once from the point where Graham Bell proved telephony to be a practical system.

The carbon transmitter of Edison and the microphone of Hughes—instruments which at their birth raised many mixed questions and agitated some angry passions—with their various modifications, are carefully considered, and the various theories of both the receiver and the transmitter are examined. We have not neglected a consideration of the many special novelties both scientific and practical, though they are chiefly the former, and we endeavour to draw conclusions of the comparative efficiency of some of the apparatus by experimental evidence. Most of what we have written on wires and cables is the result of actual experience, and we have endeavoured, as much as possible, to exclude the mere empirical and to discard all changes which have been made for the mere sake of change.

Our object has been to cover as wide a field of experience as we could command, and in doing so we may have been guilty of some omissions.

The book has expanded to a size far exceeding our original proposals; the table of contents shows the wide area we have tried to cover, but such as it is we submit it to the fair criticism of the technical world, for which it was written, in the belief that it will prove of real practical value.

We shall be greatly obliged to those who may point out any errors that may have been overlooked, or for suggestions as to any additions that would tend to extend the usefulness of the work.

We have made free use of the works of Du Moncel, Wietlisbach, Grawinkel, Rothen and others, and we have endeavoured as much as possible to give references to authorities.

We are deeply indebted to Mr. Arthur J. Stubbs, one of the Technical Officers of the British Post Office, not only for many original diagrams but for more than once repeating the task of reading over and correcting the proofs.

LONDON, *November*, 1888.

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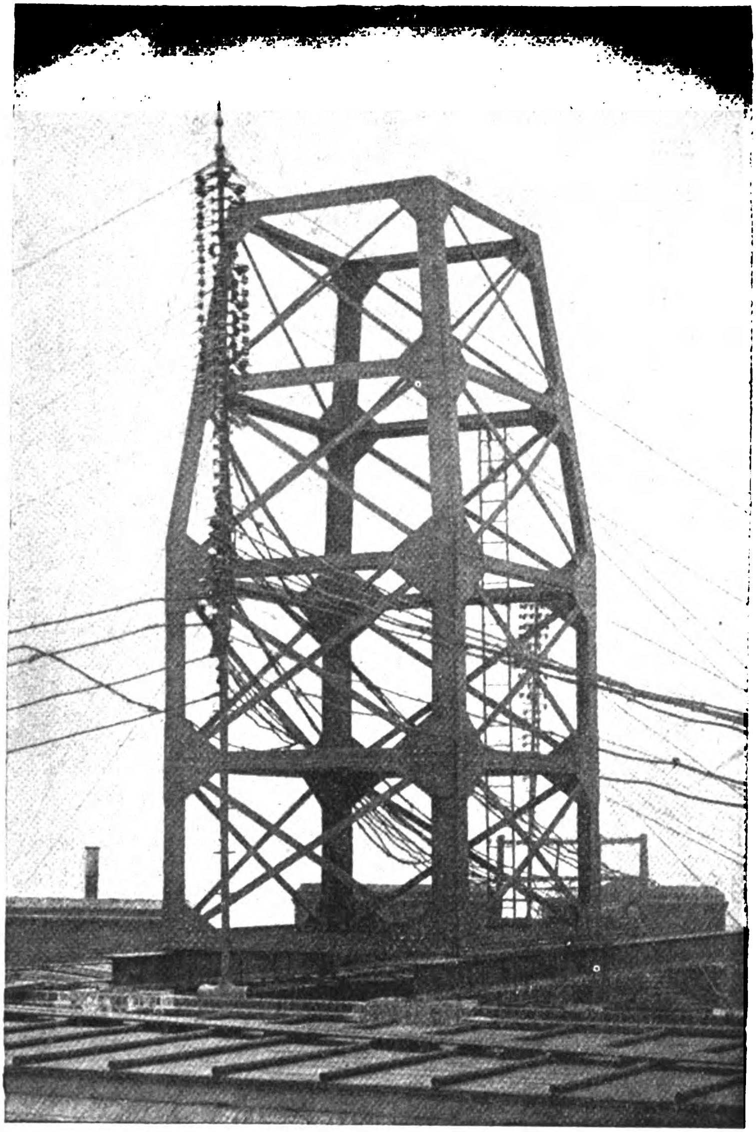

THE UNITED TELEPHONE CO.'S WIRE SUPPORT.

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THE TELEPHONE.

INTRODUCTION.

1. It is difficult to realise the fact that ten years ago little or nothing was known of the telephone. In July, 1877, one of the authors of this book brought the first pair of practical telephones to Europe. There are now 200,000 in daily use.

The idea of transmitting sound to a distance may be traced back to remote antiquity; it found its first practical expression in the construction of the speaking-tube, and in more modern times in that of the string telephone.

Robert Hooke, in 1667, described how, by the help of a tightly-drawn wire, bent in many angles, he propagated sound to a very considerable distance.

"'Tis not impossible," he says, "to hear a whisper at a furlong's distance, it having been already done; and perhaps the nature of the thing would not make it more impossible, though that furlong should be ten times multiply'd. And though some famous authors have affirm'd it impossible to hear through the thinnest plate of Muscovy glass; yet I know a way, by which 'tis easie enough to hear one speak through a wall a yard thick. It has not yet been thoroughly examin'd how far Otacousticons may be improv'd, nor what other wayes there may be of quick'ning our hearing, or conveying sound through other bodies than the air: for that that is not the only medium I can assure the reader, that I have, by the help of a distended wire, propagated the sound to a very considerable distance in an instant, or with as seemingly quick a motion as that of light, at least incomparably quicker than that which at the same time was propagated through the air; and this not only in a straight line, or direct, but in one bended in many angles."

In the "Repository of Arts," September 1, 1821, we read a description of an instrument which Wheatstone invented, and called a "*telephone*." "Who knows but by this means the music of an opera, performed at the King's Theatre, may ere long be simultaneously enjoyed at Hanover Square Rooms, the City of London Tavern, and even at the Horn's Tavern, at Kennington, the sounds travelling, like gas, through snug conductors from the main laboratory of harmony in the Haymarket to distant parts of the metropolis, with this advantage, that in its progress it is not subject to any diminution? What a prospect for the art to have music laid on at one-tenth of the expense of what we can get it ourselves! And if music be capable of being thus conducted, perhaps words of speech may be susceptible of the same means of propagation."

2. We are in this book merely concerned with the electrical reproduction of speech, and the origin of this invention dates as far back as 1837, when an American, named Page, found that a magnetic bar could emit sounds when exposed to rapid alternate magnetizations and demagnetizations. By rapidly approaching the poles of a horse-shoe magnet to a flat spiral coil

traversed by a current, he obtained a sound termed the "magnetic tick." De la Rive, Gassiot, and Marrian[1] observed the same phenomenon in a soft iron bar surrounded by a helix, at the moment when this helix was traversed by a current. Frequent interruptions of current greatly increased the effect of Page's vibrations, as they are sometimes called, and gave rise to a distinct sound of considerable intensity. When these makes and breaks were made rhythmically and rapidly a musical note was the result.

In 1854 Charles Bourseul, a Frenchman,[2] published a paper on the electric transmission of speech, in which he says:—

"Suppose that a man speaks near a movable disc, sufficiently pliable to lose none of the vibrations of the voice, that this disc alternately makes and breaks the currents from a battery; you may have at a distance another disc which will simultaneously execute the same vibrations."

" . . . It is certain that in a more or less distant future speech will be transmitted by electricity. I have made experiments in this direction; they are delicate, and demand time and patience, but the approximations obtained promise a favourable result."

Philipp Reis, of Friedrichsdorf, wrote in 1868:— "Incited thereto by my lessons in physics in the year 1860, I attacked a work begun much earlier concerning the organs of hearing, and soon had the joy to see my pains rewarded with success, since I succeeded in inventing an apparatus by which it is possible to make clear and evident the functions of the organs of hearing, but in which also one can produce tones of all kinds at

[1] *v.* Guillemin, "Le Monde Physique," tome iii., p. 730.

[2] Du Moncel, "Applications de l'Electricité," 1854.

any desired distance by means of the galvanic current. I named the instrument 'Telephon.'"[1]

Reis's instrument was in the first instance only intended for the reproduction of musical sounds, in fact, a musical *telephone*, and its application to the transmission of speech was of a very limited kind; but it contained the essential features of the present telephone, and it certainly did transmit speech.

3. For sixteen years the question of articulating telephony was shelved; improvements were made in the musical telephone by Yeates and Van der Weyde, by Cecil and Leonard Wray, and various instruments were constructed by Varley, Pollard and Garnier, and by Elisha Gray; but the speaking telephone pure and simple was only patented in the United States, by Graham Bell, on the 14th February, 1876; and, strange to say, on the very same day Elisha Gray applied for a patent for an instrument of a similar kind. Bell, with far-sighted energy, worked out and perfected his system. Gray allowed his to sleep in the American Patent Office. The question of priority between Gray and Bell was subsequently fought in the Law Courts, and ended in a compromise, one company taking up the patents of both inventors.

At the meeting of the British Association of 1876, Sir William Thomson said: "In the Canadian department I heard: 'To be or not to be, ... there's the rub,' through an electric wire; but scorning monosyllables, the electric articulation rose to higher flights, and gave me passages taken at random from the New York newspapers: 'S.S. *Cox* has arrived.' (I failed to make out the S.S. *Cox*); 'The City of New York,' 'Senator Morton,' 'the Senate has resolved

[1] "Philip Reis," by Sylvanus P. Thomson, 1883.

to print a thousand extra copies,' 'The Americans in London have resolved to celebrate the coming fourth of July.' All this my own ears heard spoken to me with unmistakable distinctness by the thin circular disc-armature of just such another little electro-magnet as this which I hold in my hand. The words were shouted with a clear and loud voice by my colleague-judge, Prof. Watson, at the far end of the line, holding his mouth close to a stretched membrane, such as you see before you here, carrying a little piece of soft iron, which was thus made to perform, in the neighbourhood of an electro-magnet in circuit with the line, motions proportional to the sonorific motions of the air. This, the greatest by far of all the marvels of the electric telegraph, is due to a young countryman of our own, Mr. Graham Bell, of Edinburgh and Montreal, and Boston, now becoming a naturalised citizen of the United States. Who can but admire the hardihood of invention which devised such very slight means to realise the mathematical conception that, if electricity is to convey all the delicacies of quality which distinguish articulate speech, the strength of its current must vary continuously as nearly as may be in simple proportion to the velocity of a particle of air engaged in constituting the sound?"

At the meeting of the same Association in Plymouth, in 1877, Mr. Preece exhibited in public, for the first time in England, Bell's developed telephone, which he had just brought from the United States; and at the same meeting Professor Graham Bell gave further illustrations.

4. Every telephone consists of a *transmitter* and a *receiver*. The transmitter is the instrument into which words are spoken, and which is applied to the mouth

or to which the mouth is applied. The receiver is the instrument which is applied to the ear, and from which sounds are received.

The telephone, as far as the receiver is concerned, has remained virtually the same as it is described in Bell's patent; alterations have been made, but more with the object of evading existing patent rights than with that of effecting improvements. It is, however, quite a different matter with the transmitter. The original Bell instrument, which is identical with the receiver, has been completely ousted as a transmitter. Instead of the original magnetic telephone, a carbon transmitter, involving the use of a battery, is now almost exclusively employed as a transmitter.

The invention of the first carbon transmitter is due to Edison, who constructed it in 1877, shortly after Graham Bell's discovery. In this instrument the vibrating plate abuts against a button of carbon. Edison ascribed the effects obtained to a variation of electrical resistance consequent upon variation of pressure.

A fresh light was thrown on this subject by the discovery of the microphone by Hughes, in 1878. He showed that the effect of Edison's carbon transmitter was not due to any influence of varying pressure on the mass of the carbon, but was a phenomenon of loose contact, and we may safely say that Hughes has done as much for the perfection of the telephone as Bell has done towards calling it into existence.

The transmitters now in use, such as Blake's, Berliner's, Hunning's, and others, are all constructed on the principle of loose contacts; they constitute the latest improvements made in this highly-interesting apparatus, and bring us down to the present time.

CHAPTER I.

SOUND AND SPEECH.

5. SOUND is excited in the consciousness by the impinging of sonorous vibrations of air upon the drum of the ear, these vibrations being transmitted to the brain by the nerves. Sound is a subjective phenomenon—that which is objective and is the basis of the science of "acoustics" is the periodic disturbance of matter transmitted in the form of wave motion, and following simple harmonic laws.

A sonorous vibration or sound wave has three distinct characteristics—*pitch*, *loudness*, and *timbre*. The pitch depends on the frequency of the wave disturbance, or on the number of vibrations executed and transmitted per second; the loudness depends on the amplitude of these waves, and the timbre on their form.

The timbre of musical as well as of vowel sounds, and consequently the articulation of human speech, is dependent on the co-existence of a certain number of components of the fundamental sound, which are called *partials*, and it is the resultant of these partials which forms the waves that produce speech.

Vowels and consonants are compound musical tones, or resultant sounds formed by the combination of these partials. The first partial which determines the pitch of the whole is called the *prime*, and the others its upper partials. The upper partials are numerous. It requires as many as eight partials to reproduce the vowel *o*. Hence the form of sound waves is very complicated, and it is marvellous that they can be reproduced by telephones.

6. Assuming, as is really the case, that the oscillations of a sounding body, or the vibrations of the molecules of air, are similar to those of a pendulum, that is to say, that they follow the same laws as the oscillations of a tuning-fork, we can graphically represent these vibrations by the curve, Fig. 1.

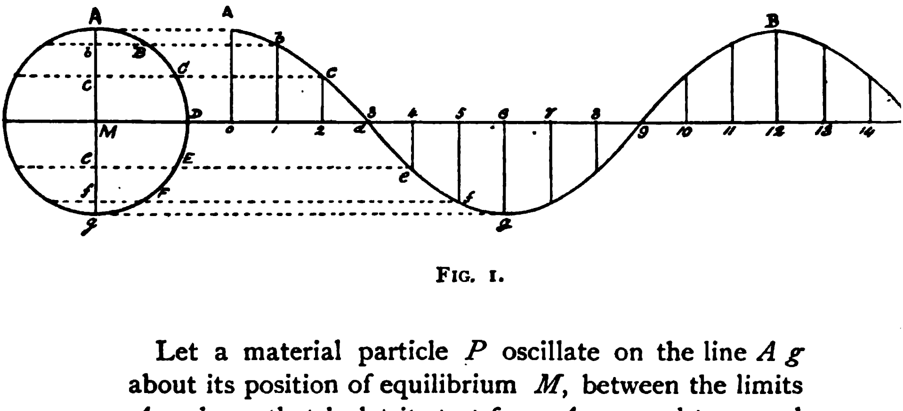


FIG. 1.

Let a material particle P oscillate on the line $A\,g$ about its position of equilibrium M, between the limits A and g; that is, let it start from A, proceed to g, and then return to A, and let it arrive after $\frac{1}{12}$, $\frac{2}{12}$, $\frac{4}{12}$, and $\frac{5}{12}$ of the whole duration T of the oscillation, at the points *b*, *c*, *e*, and *f*. Again on a line drawn at right angles to Ag from M, let equal intervals of time be marked, beginning with 0.

The points, 0, 1, 2, 3, 4, etc., follow each other at equal distances, each of which corresponds to $\frac{1}{12}$ *T*. At each of these points a line is drawn at right angles to *MD*, and on this line the corresponding value of the distance of the oscillating body from *M* is marked; thus, for instance, at

0	length	$0A$	$= MA$	$= a \times \cos 0$
1	„	$1b$	$= Mb$	$= a \times \cos 30^\circ$
2	„	$2c$	$= Mc$	$= a \times \cos 60^\circ$
3	„	0	$= 0$	$= a \times \cos 90^\circ$
4	„	$4e$	$= Me$	$= a \times \cos 120^\circ$

And generally $y = a \cos \theta$, a being the distance *MA*, and θ the angle which the radius to any point on the circumference of tne reference circle *ADg* makes with *MA*.

The curve drawn through the points *A*, *b*, *c*, 3, *e*, *f*, *g*, etc., is the *curve of vibration of a body oscillating after the manner of a pendulum, and following the law of simple harmonic motion.* This is more frequently expressed thus: $y = a \sin \phi$, ϕ being the complement of θ, or the angle which *MD* makes with the axis as it revolves about *M* in the positive direction. It forms what is called a *sinusoidal curve* or *curve of sines.* The interval between two crests of waves *AB* is called the *wave length.* The distance *MA* through which the particle vibrates is called the *amplitude* of the vibration. The whole duration *T*, which is represented by the time 0 to 12, is called the *period* of the vibration. The amplitude and period of a vibration are quite independent of each other. The oscillating particle will make the same number of vibrations per second whether the amplitude of its excursion be great or small. This equality of period for all amplitudes is called *isochronism.* If a tuning fork be set in vibration, its note or pitch depends solely on the number of excursions to and fro per second, but its loudness is dependent on the extent of these excursions, that is, the amplitude. Hence, while the note does not change, the loudness does, and the sound dies away as the amplitude diminishes.

Such a simple harmonic curve can be actually produced by providing a tuning-fork of a rather large size with a pen or stylus, which during its oscillation leaves traces on a strip of paper which is drawn from under the tracing stylus with uniform velocity, in a direction at right angles to the line of vibration.

7. The motion of an oscillating body, however, may

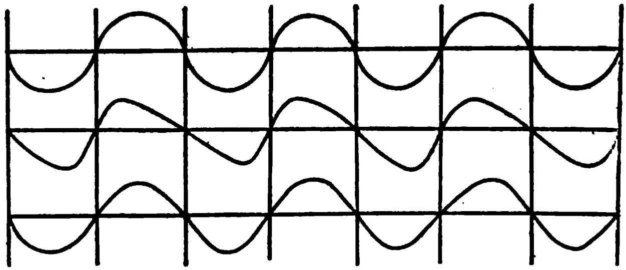


FIG. 2.

with equal periods and equal amplitudes follow any other form besides the one expressed by the above curve. But, whatever this form may be, it can in a similar manner be represented as a curve by marking, as in Fig. 1, on a horizontal line lengths which are proportional to the time elapsed since the commencement of oscillation, making the ordinates proportional to the corresponding distance of the oscillating point from its position of equilibrium, and joining the points thus obtained by a curve.

Fig. 2 shows three different curves of vibration, which correspond to equal periods and amplitude. The top curve represents the motion of a simple pendulum, the other two correspond to a motion which deviates from the swinging of a pendulum, and it is to this difference in the form of vibration that the difference of "timbre" must be ascribed.

8. The vibrations of a sounding body give rise in the surrounding atmosphere to a wave-motion which is transmitted by the successive molecules of air executing similar vibrations as the vibrating body itself. When a tuning fork vibrates in air it gives to the air a series of pushes, each of which produces a momentary increase of pressure and density in front of the advancing prongs, while a momentary decrease of density and pressure is produced behind them. As the prongs advance, first in one direction and then in the opposite, a series of compressions and extensions are produced in alternate succession. But each compressed portion tends to relieve itself by expanding into the neighbouring air, which is thus in its turn compressed, and the extended portions in like manner communicate extension. Hence a series of compressions and extensions are propagated through the surrounding air, and these constitute an undulation whose period is the same as that of the vibrations of the tuning fork. If the sonorous vibrations take place in open space their amplitude must get smaller and smaller, and the sound will die away. If the air waves impinge on a diaphragm of any kind, the diaphragm will take up the sonorous vibrations and oscillate with the same period and the same form. The diaphragm becomes a sounding body. If, therefore, the sounding body itself oscillates after the manner of a pendulum, the vibrations of the molecules of air which

transmit its sound must follow the same simple harmonic law. A difference in the form of vibration of a sounding body causes a similar change in the form of vibration of the particles of air by whose oscillation the sound of that body is transmitted to the ear. The difference of timbre is therefore caused by the differences in the form of vibration of the sound-waves which reach our ear.

The theory of vowel sounds as propounded by Helmholtz has been amply confirmed by subsequent investigators.[1] The formation of consonants follows the same laws, and the difference in timbre of different voices, or the variation in intonation and articulation which distinguishes one human being from another, is due to the form of the sonorous vibrations produced by each, and therefore to the number and character of the partials superimposed upon the prime tone by the peculiar formation of each mouth, lips, and teeth.

No satisfactory explanation has yet been made of the *rationale* of sibilant sounds. They are the most difficult to obtain on the telephone, and it is not certain that they ever are properly reproduced. Echoes do not repeat them, though they are reflected in whispering galleries, as in the dome of St. Paul's; but the separation of the air space in which they are produced by a diaphragm seems to destroy them. They are probably something of the nature of the breakers in a water wave, though how produced theory does not explain. Their influence on the tympanum of the ear in the unbroken air-space of a restaurant or theatre is remarkable, and a good hiss never fails to attract attention above a perfect babel of other sounds. The

[1] Preece and Stroh, "Studies in Acoustics," Proc.: Royal Society, No. 193. 1879.

scund or crack of a whip has very much of the same character, but no record exists of the transmission of this sound by telephone.

9. Now, the function of a telephone is to convert at one place the energy of these sonorous vibrations into the energy of electric currents, which shall in their turn, at some other place, be converted into the energy of magnetic attractions and repulsions, which shall again be converted into sonorous vibrations, and so reproduce the original sounds.

Intermittent currents of electricity may be graphically represented in the same way as in Fig. 3, where the

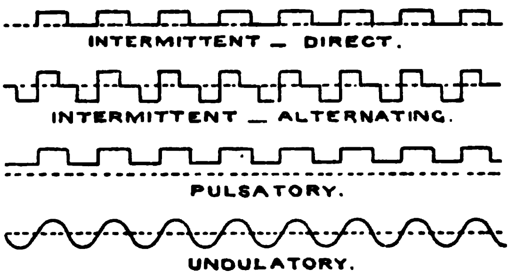


FIG. 3.

small squares on the top line show an intermittent current flowing in the same direction, whilst those on the second line show an intermittent current flowing alternately in a positive and negative direction. Such lines would be traced by the pen of such an instrument as Sir William Thomson's syphon recorder, so much used in working submarine cables; or they would be found geometrically as in Fig. 1 if we conceived the ordinates of the sinusoidal curve to represent the strength or current flowing at any moment. Currents of this description are used in musical telephones; they reproduce simple musical sounds with their original pitch without timbre, being adapted to convey the number of the air vibrations which give to them their intermittent character.

A second kind of current is produced by suddenly varying, by some means or other, the strength of a continuous current, as shown in the third line; it is called a *pulsatory* current. These pulsatory currents too find application in the musical telephone and are capable of transmitting sounds of varying intensity, but not of timbre.

If, finally, a continuous current varies in strength, not suddenly and, as it were, by jerks, but gradually ascending and descending according to the harmonic law, as shown in the bottom line, an *undulatory* current is the result; the flowing electricity is, so to speak, thrown into undulatory motion, so that the waves are produced, not by the generation of a current, or by its growth to a certain height and decline to zero, but by variations of current strength within certain distinct limits and in a distinct form.

Hence in working telephones the electric currents always assume the sinusoidal form, and follow the simple harmonic law.

The task of the telephone, therefore, resolves itself into one of the *electrical transmission of harmonic vibrations.*

These vibrations, as we have seen, can be graphically represented by a curve, and, therefore, currents, in order to be able to reproduce these vibrations, must adapt themselves, as far as this form of motion is concerned, to a similar law, or in other words, they must be such as can be graphically represented by similar curves.

CHAPTER II.

INDUCTION.

10. An electric current is always accompanied by certain magnetic properties, which vary with the direction of the current, with its strength, and with the rate at which the strength rises and falls. The direction of a current is defined conventionally by reference to that which flows from the copper to the zinc pole outside a Daniell cell, called the *positive* current. The strength of a current is measured by the intensity of the magnetic effects which it produces in its neighbourhood; and the rate at which the strength varies is measured by certain inductive effects which form the subject of this chapter. The neighbourhood of a current is a *magnetic field*, and Faraday has shown how we can indicate the intensity and direction of this field by assuming it to be traversed by lines of force whose number, per unit area, at right angles to their direction is proportional to the intensity of magnetic force in the field, and whose direction is that along which a very small north pole would be moved if placed in that field. The space all around a conductor through which a current is flowing can thus be mapped out by circles having the axis of the conductor for their centre, and if the positive current is flowing along the conductor away from the observer, then a north pole

would tend to move in a direction similar to the motion of the hands of a watch facing the observer, along any one of these closed curves of force. A south pole would of course be urged in the opposite direction; hence the two poles of a magnet in the neighbourhood of a straight conductor are influenced by opposite forces which tend to place the magnet at right angles to the direction of the current and tangential to the line of force. This very useful rule enables one to determine at once the direction in which a magnet is deflected by a current, and it also indicates how an iron bar is magnetised, for if we conceive a circular line of force to become a conductor, and the straight conductor to become a bar of iron, then a positive current flowing in the direction of the hands of a watch will induce a north pole *away* from the observer.

Now, currents and magnetic fields are so related that any change in the current produces a change in the magnetic field, and any change in the magnetic field produces a change in the current. In fact, if there be a magnetic field, and a conductor in that field, any change in that field will produce the conditions that determine a current in that conductor. Indeed, it is correct to say that if a conductor forming part of a closed circuit be moved *across* a magnetic field in a direction at right angles to the lines of force in that field, a current will be induced in that conductor whose strength is proportional to the strength of the field and to the rate at which the conductor cuts the lines of force; and conversely, if the conductor be fixed and the lines of force be projected through the field at right angles to the conductor, a current will be induced in the conductor whose strength is proportional to the intensity of the field, and to the rate at which the lines of force are projected through the field. Thus motion either of the conductor or of the lines of force is accompanied by induction.

11. We have thus two classes of induction: that in which changes of the current in a primary conductor produce secondary currents in a neighbouring or secondary conductor, called *electrodynamo*—or *current-induction*; and that in which changes in the magnetic field produce currents in a conductor in that field, called *magneto-electric induction*. The latter effect can be produced either by the motion of a permanent magnet or of an electro-magnet, or by the motion of a conductor conveying a current, or by the motion of the armature of a magnet.

The direction of the secondary current is determined by the law of Lenz, which asserts that such a current produces effects which oppose the motion of the prime inducer. Hence any sudden increase of a primary current induces a secondary current in the *opposite* direction, and any sudden decrease induces a secondary current in the *same* direction. Similarly any sudden approach of the primary current towards the secondary circuit induces a secondary current in the opposite direction, and any sudden withdrawal of the primary circuit induces a secondary current in the same direction. Both these effects arise from the fact that the secondary circuit is cut by lines of magnetic force in such a direction as to fulfil Lenz's law, and they occur whether the lines of force are produced by currents or by magnets. In fact, currents are produced in a closed circuit placed in a magnetic field whenever any change whatever occurs in the intensity of that field.

12. The most effective mode of producing secondary currents is by an *induction coil*, which consists usually of an iron core (made up of a bundle of soft iron wires to facilitate rapid magnetisation and demagnetisation), surrounded by a thick primary wire of small resistance, which in its turn is surrounded by a fine secondary wire of great resistance. The ratio of the secondary current to the primary, if the wires are of the same gauge, is dependent simply on their relative lengths or on the number of turns which each makes; and if they are of different diameters, then the ratio is dependent on the product of the number of turns and their resistance. It is a remarkable fact that the energies in the primary and secondary circuits are very nearly equal to each other, and, indeed, in a theoretically perfect coil they would be exactly equal, but through mechanical and magnetical imperfections this perfection cannot be quite reached. Now the energy of a current in a coil, at any moment, is expressed by the product of the electromotive force (E) at the terminals of the coil producing the current, and the current itself (C), that is W = EC. Hence in a theoretically perfect coil

$$E_1 C_1 = E_2 C_2$$

or

$$\frac{E_1}{E_2} = \frac{C^2}{C_1}$$

If e be the E.M.F. of each turn of the wire in either coil (for every turn may be considered as practically equal and is in the same field), then, if n be the number of turns

$$E_1 = n_1 e$$

$$E_2 = n_2 e$$

Hence

$$\frac{E_1}{E_2} = \frac{C_2}{C_1} = \frac{n_1}{n_2}$$

so that we can regulate the ratio of E.M.F. and current at will, by varying the relative number of turns of wire. Hence by increasing the number of turns in the secondary circuit, and thereby increasing its resistance, we can make the current as small as we like, and the E.M.F. as high as we like. Thus the astounding effects of Ruhmkorff's coil are explained.

13. There is a remarkable cause of disturbance to this theoretical perfection in the presence of a secondary effect in all coils, due to electro-magnetic inertia. If you take a helix, and start a current through it, and regard one turn of the coil, then this turn will set up a magnetic field which will project lines of force through every other turn of the helix, in such a direction as to set up an opposing E.M.F. to the prime current, and every other turn will act in the same way, so as to tend to set up a total E.M.F. opposing the flow of the prime current, which will vary with the square of the number of turns (n^2). When the prime current ceases, the reverse action takes place, the E.M.F., excited by the motion of the lines of force in the opposite direction, acts in the same direction as the prime current, and tends to prolong its flow. This effect of *self-induction* is to retard the rate of increase of current at its commencement, and its rate of decrease at its cessation, and so to modify the production of secondary currents. It is considerably influenced by the mass and arrangement of the iron present, and hence bundles of soft iron wire are used to facilitate the rapid disappearance of the magnetic field.

The effect of self-induction is very marked with periodic currents of rapid alternations, and we shall find, as we proceed with our subject, that it materially affects the clearness of articulation of telephones, and seriously impedes the efficiency of the service. Its effect is not confined to one helix or to theapparatus. It is not possible in any circuit to establish a current instantaneously at its maximum strength, or to let it suddenly cease to flow. Hence, self-induction limits the number of currents which can be transmitted per second. Every circuit, whether a helix or not, has a co-efficient of self-induction, called L, and a time constant $\frac{L}{R}$ which enables calculations to be made to determine the effect of electro-magnetic inertia. The opposing E.M.F. set up, acts as a resistance, and it is sometimes called a *spurious* resistance, but it differs from pure resistance, in the fact that it does not dissipate energy by getting hot; it stores it up, or renders the energy potential. It throttles or chokes a coil when conveying periodic currents, and we shall see how this apparently injurious effect is utilized in practice.

CHAPTER III.

THE BELL TELEPHONE.

14. EVERY telephone, whatever may be its construction, consists of two distinct parts:—

1. The transmitter, which transforms the energy of the sonorous vibrations of the spoken words of the sender into periodic currents which are sent along the line.

2. The receiver, which, as the name implies, receives the periodic currents, and transforms them again into sonorous vibrations which reach the ear of the listener.

The characteristic properties of magnetic telephones are, first, the absolute identity and reversibility of transmitter and receiver; and, secondly, the fact that they present a complete magnetic system worked without battery.

The first and simplest of all magnetic telephones is the Bell Telephone.

The first form of this instrument, constructed by Professor Graham Bell, in 1876, is shown in Fig. 4.[1] A harp of steel rods was attached to the poles of a permanent magnet NS. When any one of the rods was thrown into vibration, undulatory currents were induced

[1] "Journal of the Society of Telegraph Engineers," 1877, October 1st, 403.

in the coils of the electro-magnet E, through the disturbance of the magnetic field in which it was placed, passing through the wire L to the electro-magnet E_1, by varying its magnetisation attracted the rods of the harp, H_1, with varying force throwing into vibration that rod which was in unison with the one vibrated at the other end of the circuit. Not only so, but the amplitude of vibration of the one determined the amplitude of vibration of the other, for the strength of the induced current was determined by the amplitude of the disturbing vibration, and the

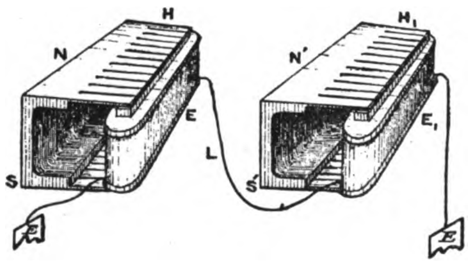


FIG. 4.

amplitude of the vibration at the receiving end depended upon the strength of the induced currents. When we sing into a piano, certain of the strings of the instrument are set in vibration sympathetically by the action of the voice with different degrees of amplitude, and a sound, which is an approximation to the vowel uttered, is produced from the piano. Theory shows that, had the piano a much larger number of strings to the octave, the vowel sounds would be perfectly reproduced. It was upon this principle that Bell constructed his first telephone. The expense of constructing such an apparatus, however, deterred Bell from making the attempt, and he sought to simplify the apparatus before proceeding further in this direction. After many experiments with more or less unsatisfactory results, he constructed the instrument shown in Figs. 5 and 6, which he exhibited at Philadelphia in 1876.

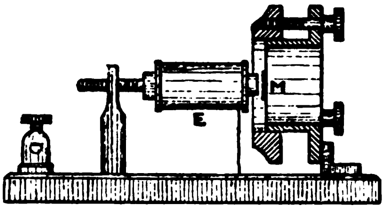


FIG. 5.

In this apparatus, the transmitter (Fig. 5) was formed by an electro-magnet E, through which a current flowed, and a membrane M, made of gold-

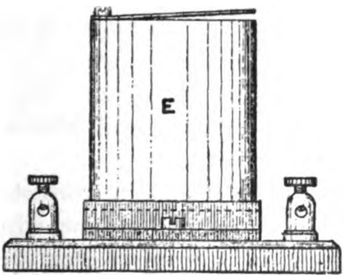


FIG. 6.

beater's skin, on which was placed as a sort of armature a piece of soft iron, which thus vibrated in front of the electro-magnet when the membrane was thrown into sonorous vibration.

The receiver (Fig. 6) was formed of a tubular electro-magnet E, consisting of a vertical single coil electro-magnet, enclosed in a soft-iron tube, upon which was fixed by a screw a thin armature of sheet iron slightly tilted, as shown, of the thickness of a strong piece of paper, which acted as a vibrator; a small bridge placed on the socket acted as a sounding box.

It must, however, be remarked that the apparatus thus constituted was not a magnetic telephone pure and simple, for a battery of several elements was placed in the circuit of the apparatus. It was, however, of immense service, for it enabled Bell and his friend Watson to experimentally study telephonic transmissions. It was the instrument that Sir William Thomson saw in 1876.

15. After numerous experiments made with the intention of discovering empirically the exact effect of each element of the combination, the membrane of goldbeaters' skin used in the instrument (Fig. 5) was discarded, and a simple iron plate used instead, and further—and this is the most important point in the improved apparatus—Bell superseded the battery by a permanent magnet to produce the magnetic field. This, indeed, appears to have been his original idea, as is indicated in his first telephone (Fig. 4).

In its new form the telephone consisted of a permanent bar magnet, with a coil of fine wire at one end, suitably mounted in a wooden box behind an iron diaphragm ; but a still more powerful form of apparatus was constructed by using a powerful compound horseshoe magnet in place of the straight rod which had been previously used. As shown in Figs. 7 and 8, upon each pole-piece of this magnet a small coil, B B′, was placed, and the diaphragm M—a thin iron disc—was fixed on a separate block in front. On the side of the block next the diaphragm was a shallow cavity to leave M free to vibrate, and a hole through the block communicated with a mouth or ear piece E. By loosening the

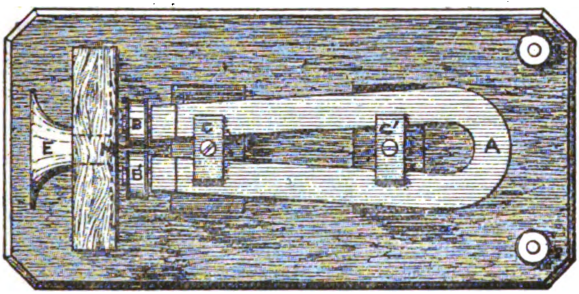


FIG. 7.

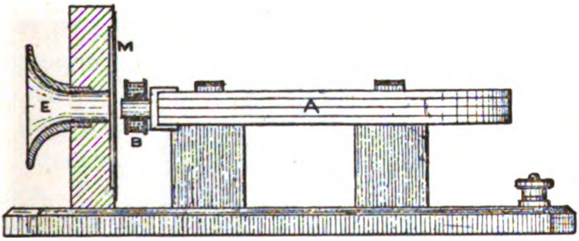


FIG. 8.

clamping-pieces C, C^1, the position of the magnet A, with regard to the diaphragm, could be adjusted.

This, the first practical magnetic telephone, was exhibited in the Essex Institute, in Salem, Massachusetts, on the 12th February, 1877, on which occasion a short speech shouted into a similar telephone in Boston sixteen miles away, was heard by an audience in Salem, while the enthusiastic applause of the Salem audience was distinctly heard at Boston.

16. From the form shown in Figs. 7 and 8 to the present form of the instrument (Fig. 9) is but a step. It is, in fact, the same arrangement in a portable form, a bar magnet being placed inside a handle, and a more con-

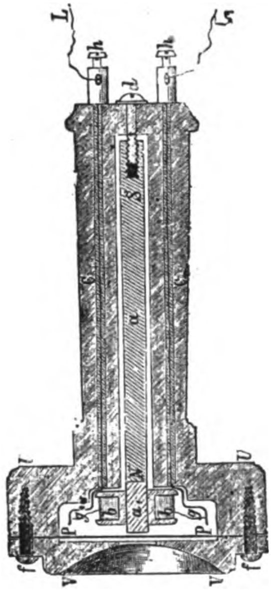


FIG. 9.

venient form of mouthpiece provided. Professor Peirce, of Brown University, Providence, Rhode Island, was the first to demonstrate the extreme smallness of the magnets which might be employed, and he also invented the mouthpiece shown in Fig. 9.

In this the latest form given to it by its inventor the instrument consists of a small wooden or ebonite case *c c*, which contains the magnet *a* placed opposite the vibrating plate P P, and serves at the same time for holding the instrument in the hand. By means of a screw *d* placed at the extremity of the handle, the magnet *a* can be brought near the vibrating plate P P, or removed from it; and this constitutes the adjustment of the instrument.

The magnet *a* is a hexagonal permanent bar magnet of the best steel, about 4½ inches long and ½ inch in diameter. Upon its N end, which is turned true, is placed a small boxwood reel *b b*, which is wound with insulated copper wire generally to a resistance of about 40 ohms. The ends of this coil are connected to two terminals at the end of the case.

The vibrating plate, which has a diameter of 2 inches in its free part and a thickness of from 1/100 to 1/50 of an inch, is of sheet iron and is either tinned or coated with varnish to prevent its oxidation. The ferrotype plate used by photographers is found to be most suitable for a diaphragm of the diameter given. The mouthpiece *v v* screws on to the box either by independent screws, as in Fig. 9, or by a screw channel; and the vibrating plate, squeezed between it and the box, is thus kept in position.

17. The action of the telephone may be summed up in a few words. The iron diaphragm acts as a sort of armature to the magnet, and any motion imparted to it changes the magnetic field in which the coil fixed at the end of the magnet is placed. The conditions for a complete circuit are shown in Fig. 10, in which the parts of the telephones at S_1 and S_2 are marked the same as in Fig. 9.

On speaking before the mouthpiece of the telephone at S_1 the plate M is thrown into harmonic vibrations; these vibratory motions modify the field of the magnet A, and thus excite currents in the coil placed at its extremity. The telephone is in fact a real generator of electricity—a generator of marvellous sensibility, which varies the strength and form of the periodic currents it generates, and makes them follow all the varying and complicated undulations which characterise articulate sounds.

The periodic or undulatory currents thus developed in one telephone by the vibrations of the plate are conveyed to a second telephone, placed at any distance away, which re-transforms them into sonorous vibrations. When these periodic currents pass through the coil B′ of the receiving telephone, they increase the magnetisation of the bar if they traverse the coil in a direction favourable to magnetisation, and diminish it if they are of inverse direction; the plate M obeys these changes of magnetisation, approaches the coil when the magnetic force increases, withdraws from it by its own elasticity when the force diminishes, and

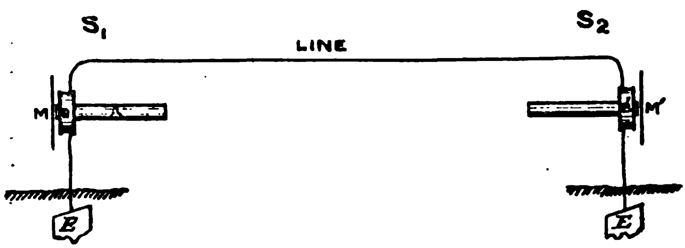


FIG. 10.

by this undulatory action, aided probably by molecular disturbance, which results from the exciting currents, vibrates in unison with the plate of the transmitter, and so reproduces the sonorous vibrations, although with perceptibly smaller displacements, and therefore with reduced loudness.

The telephone certainly is one of the most beautiful illustrations of the equilibrium and the unity of natural forces—an equilibrium so nicely balanced, that no change, however slight, can take place in one of them without immediately producing a corresponding change in the other. The mechanical effect developed by the emission of sonorous vibrations is very slight, and yet the telephone reproduces its echo at a distance of several hundred miles.

18. The extreme sensitiveness of the Bell telephone is well shown by the following experiment made by Dr. Werner Siemens[1]:—A Bell telephone, whose magnet pole was surrounded by 800 convolutions of copper wire of 1 mm. diameter and 110 ohms resistance, was placed in circuit with one Daniell element. By means of a commutator contained in the circuit, the current could be reversed 200 times per second; and when the commutator was set into continuous motion undulations were obtained which produced in the telephone a loud crackling noise. The primary coil of a small induction apparatus was then placed in the commutator circuit whilst the telephone was in the circuit of the secondary coil, so that, when the commutator was set in motion, the currents induced in the secondary coil acted on the telephone. A loud noise was produced, even on inserting 50,000,000 ohms resistance, and this noise remained audible when the secondary coil was pushed back to the very end of the primary one, thus reducing the inductive action of the primary coil to a minimum, and placing it beyond the reach of measurement.

Mr. Preece has lately determined[2] that a Bell receiver

[1] Dr. Werner Siemens, "Monatsberichte der Berliner Akademie für 1878."

[2] British Association, Manchester, 1887.

will respond to a current which may be expressed thus:—6×10^{-12} ampère, or thus—·000,000,000,000,6 ampère; that is, six ten-thousand-millionths of a milliampère.

Pellat[1] obtained similar results by a different method. A condenser of microfarad capacity was charged 160 times per second by connecting it with two points of a circuit, and discharged through a telephone. If K is the capacity, V the difference of potential at the terminals, the expended energy for n charges and discharges is $n\text{KV}^2$. If V is reduced to .0005 volt, a tone is still heard in the telephone, although the energy is so small that it could only produce one small gramme-degree heat unit in 10,000 years. With this small quantity of heat, therefore, the telephone might be made to reproduce sounds during 10,000 years.

The great sensitiveness of the Bell telephone is the more remarkable when we consider the various transmutations of energy it effects. The organs of speech produce in the first instance sonorous vibrations, which, impinging upon the diaphragm, give rise to oscillations which in their turn result in rapid changes of the field of the magnet, and consequently in the production of induced currents in the coil placed in that field. These induced currents are conveyed by the line wire to the coil of the magnet in the receiving instrument, produce analogous changes of magnetisation in the magnet, and result, partly through attraction of the mass and partly through molecular action, in vibrations of the diaphragm of the receiver. The vibrating diaphragm imparts its motion to the surrounding air, and gives rise to sonorous

[1] Pellat, "Journal de Physique," x., p. 358, 1881.

vibrations which strike the tympanum of the ear. We have here no less than eight distinct transmutations and transformations of energy, each of which is accompanied by a certain unavoidable loss of energy. Further losses, also, arise from inductive action of neighbouring wires, leaks through the supports of wires, electro-static and electro-magnetic induction, etc. It is, therefore, quite evident that the receiver can in no case emit sounds of the same intensity as those expressed before the transmitter.

CHAPTER IV.

CARBON TRANSMITTERS.

19. It is quite clear that when we speak into a Bell transmitter only a small fraction of the energy of the sonorous vibrations of the voice can be converted into electric currents, and that these currents must be extremely weak. Edison applied himself to discover some means by which he could increase the strength of these currents. Elisha Gray had proposed to use the variation of resistance of a fine platinum wire attached to a diaphragm dipping into water, and hoped that the variation of extent of surface in contact would so vary the strength of current as to reproduce sonorous vibrations; but there is no record of this experiment having been tried. Edison proposed to utilise the fact that the resistance of carbon varied under pressure. He had independently discovered this peculiarity of carbon, but it had been previously described by Du Moncel, who enounced it in the following words: "The pressure exercised between two conducting bodies abutting against each other has a considerable influence upon the strength of the current," and also: "The increase of current strength with the pressure exercised at the point of contact is the greater the higher the resistance of the conductors, the less hard they are, and the cleaner their surface."

Du Moncel's claim was acknowledged by Sir W. Thomson in the following words: "It is true that the physical principle applied by Edison in his carbon telephone and by Hughes in his microphone is the same; but it is also the same as that employed by Clérac, of the French Telegraph Office, in his variable resistance tube, which he had lent to Mr. Hughes and others, in 1866, for some important practical applications. This apparatus is, however, entirely dependent upon a fact enounced a long time ago by Du Moncel—*that*

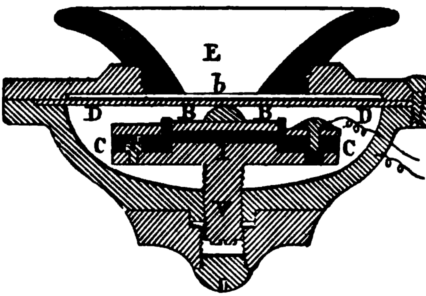


FIG. 11.

the increase of pressure between two conductors in contact produces a diminution in their electrical resistance."

Edison's Carbon Transmitter.

20. The first carbon transmitter was constructed in 1878 by Edison. After passing through various stages the instrument finally received the form represented in Figs. 11 and 12. It consists of an ebonite mouth-piece, E, a vibrating plate, D, and a disc of prepared carbon, I, of the size of a shilling, withdrawn from or brought near to the vibrating plate by means

of a screw V at the back part of the transmitter. A small platinum plate, B, with a rounded ivory button, *b*, is fixed to the upper surface of the carbon disc. The vibrations of the membrane are communicated to the carbon by the small platinum plate. According to the inventor the variations of pressure produced by these vibrations cause a variation of electrical resistance in the carbon (placed in circuit with a battery and an ordinary

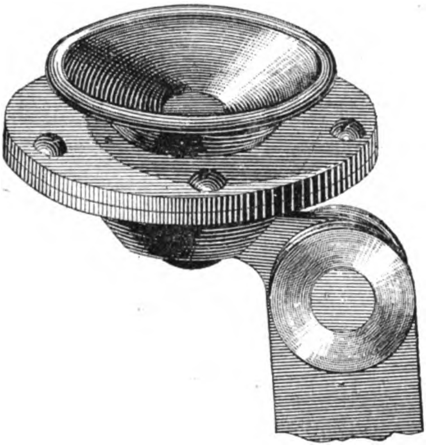


FIG. 12.

Bell receiver), and cause it to vibrate in unison with the diaphragm. In practice, the current of the battery, transformed by the transmitter into an undulatory current, traverses the primary wire of a small induction coil, which induces in the secondary wire secondary currents that actuate the receiver at the other end.

The function of the transmitter in carbon transmitters is restricted, as we have seen, to the production of variations of electrical resistance in the circuit; these variations immediately occasion proportionate variations, in an inverse sense, in the strength of the primary current. For a given vibration, the change in the resistance of the circuit will have a given value, which we will assume, for argument's sake, to be 1 ohm. If the entire circuit has a small resistance—ten ohms for instance—the variation of 1 ohm produced in the transmitter will vary the current strength by $\frac{1}{10}$ of its total value, and consequently the receiver, which acts under the influence of these variations of current, will vibrate with great energy, and produce a certain sound. If, on the contrary, the total resistance of the circuit is large—1,000 ohms for instance — the variations of current will be only $\frac{1}{1000}$ of the total current strength, the receiver vibrating with less energy and the sound being much less.

To obtain, therefore, an equally powerful effect in this case as in the other, it would be necessary to increase the number of battery elements and also to increase the variations of resistance of the transmitter. This is clearly neither practical nor economical.

21. Edison cleverly got over the difficulty by employing an arrangement applied already in 1874 by Elisha Gray to his musical telephone. Instead of causing the current passing through the transmitter to traverse the line, Edison simply passed it through the primary wire of an induction coil. One of the extremities of the secondary wire is then connected to earth, the other end is connected to the line traversing the receiver and going to earth. The transmitter now acts only in connection with a small resistance, represented by the battery, the transmitter itself and the primary wire, and consequently the variations of resistance of the transmitter have a consider-

able relative magnitude. These variations of resistance manifest themselves in the primary wire by corresponding variations of current strength, and in the secondary wire by induction currents of proportional amplitude and high electro-motive force according to the size of the wire and its number of turns (§ 12). In virtue of this latter property they can overcome large resistances, and we can thus telephone to considerable distances with an initial current of low electro-motive force. The action of the apparatus is as follows:—On speaking before the mouthpiece E (Fig. 11), the diaphragm vibrates, and these vibrations produce, through the intermediary of stud *b* and plate B, variations of pressure in the carbon disc I. The resistance of the carbon disc is thus varied exactly in accordance with the number and amplitude of the vibrations of the diaphragm. To these variations of resistance correspond variations of strength of the battery current. This current flows through the primary wire of the induction coil, producing induced currents in the secondary wire, passing from there to the line which is connected with the receiver (an ordinary Bell telephone) at the receiving station. The effect produced in the receiver is exactly the same as in the case of a Bell telephone acting as transmitter, and has been described in the preceding pages (§ 17).

The performance of this carbon transmitter was by no means satisfactory, and it is very doubtful if the above explanation of its action is accurate. Professor Hughes[1] in 1878 read a paper before the Royal Society, in which he introduced the microphone, an instrument that operated from another principle, viz., the variation of resistance in a loose contact when traversed by a current.

[1] Proceedings of the Royal Society, May, 1878.

Hughes' Microphone.

22. The microphone is nothing but a telephonic transmitter, but it owes its name, which was given it by its inventor, to its power to convert vibrations of feeble intensity into undulatory currents, which, passing through a receiving telephone, produce sonorous vibrations of much greater intensity than those of the original source. It performs therefore in acoustics, with

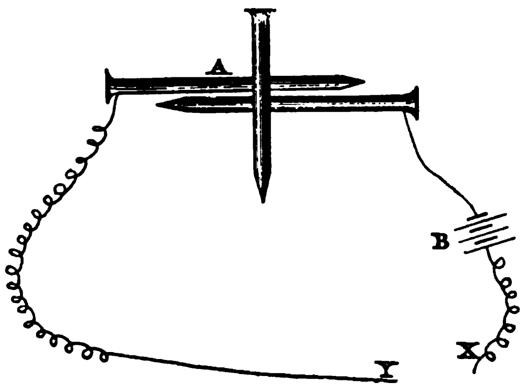


FIG. 13.

regard to feeble sounds, the same part as the microscope does in optics as regards small objects.

We must, however, guard against the belief that the analogy between the microscope and the microphone goes further than the effect produced by the two classes of instruments; there is nothing to prove that we have to do with an amplification of the sounds themselves; on the contrary, it seems more probable that it is rather a question of transformation of molecular movements into sonorous vibrations than one of actual amplification.

Amongst the earliest forms which Professor Hughes gave to this instrument is the form shown in Fig. 13. He took two French nails, laid them side by side, not touching each other, and bringing the ends of the wire in contact with them, and laying between or across them a third and similar nail, he was able to reproduce

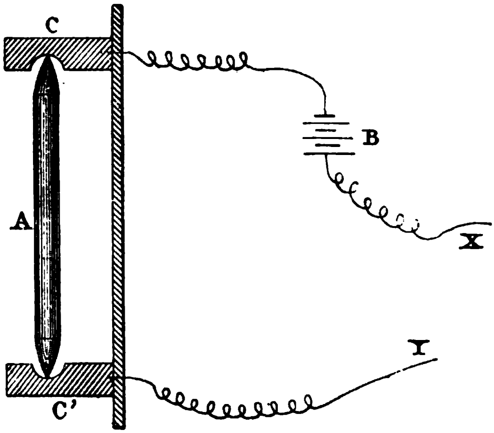


FIG. 14.

in a telephone fixed between X and Y almost perfectly the sound of a clock, and more than that, he began to get indications of the sound or tone of the voice. The apparatus, in fact, constitutes a real telephonic transmitter. Words spoken, airs sung to this little nail, which can dance on the two others to the sounds or the notes emitted, are instantaneously transmitted to the receiver at the other end of the line with marvellous clearness and power.

The effect produced is better still with carbon pencils, and the apparatus employing carbon, which has, with a few unimportant modifications, remained *the* microphone "par excellence," is represented in Figs. 14 and 15. It consists of a small pencil of gas carbon A terminating in a point at each end; the two ends rest lightly within two small circular holes in two pieces of carbon C C′, and the carbon pencil takes up a vertical position between them; C and C′ are fixed to a thin sounding board, which

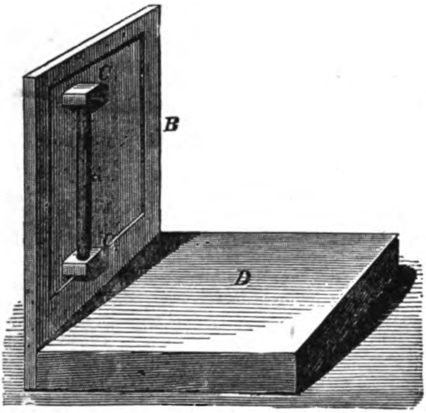


FIG. 15.

is placed on a solid block D (Fig. 15). The pieces C and C′ are connected by the wires X and Y to the battery and to the line wire leading to the receiver. The instrument, rough as it looks, is of surprising delicacy.

It converts into sonorous vibrations not only musical sounds and words, but the slightest oscillations and even an imperceptible rustling. The slightest touch, the least friction against the block, is sufficient to produce a grinding noise in the telephone. The point of a small brush rubbing against the block, the fall of a small cotton ball, produce a perfect uproar in the receiver; a fly or any other insect walking is distinctly heard by a person at a distance of over a mile from the transmitter.

The difference between Edison's carbon transmitter, and the microphone in its simple form as constructed by Hughes is very slight; but the Edison form has disappeared, and in the same way as all magnetic telephones are more or less imitations or modifications of the original Bell instrument, so all carbon transmitters are now modifications of Hughes' ingenious apparatus. The number of these imitations is legion; but most of them are modifications without much practical value. We cannot examine all these apparatus; we shall confine ourselves to the description of those modifications which represent real improvements, and which have given satisfactory results in practice.

CHAPTER V.

THEORY.

The Telephone.

23. THE following figure (Fig. 16) gives a general idea of the field (§ 10) about a Bell telephone. The resultant effect of the iron disc is probably to shift the pole at B nearer to the end of the magnet. The disc itself becomes, as it were, part of the pole. The coil of wire

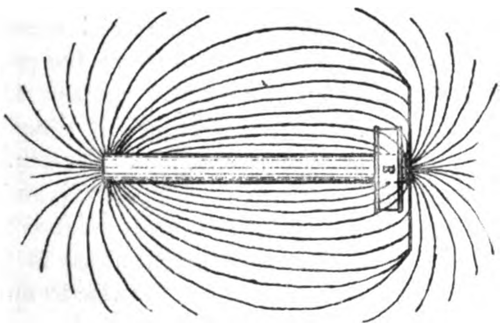


FIG. 16.

is permeated by lines of force, and any vibration or displacement of the disc vibrates or displaces these lines of force.

If we want to get a clear idea of the *modus operandi* of the reproduction of sound by means of the Bell telephone we must examine what happens

1. In the transmitter.
2. In the receiver.

The sonorous vibrations due to the voice, intensified by the conical shape of the mouthpiece (Fig. 8), transmit their energy to the elastic membrane, or diaphragm, and this latter reproduces in its movements, with all their variations of pitch, amplitude, and timbre, those of the air, itself set in vibration by the voice. The movements of the diaphragm, as it approaches or withdraws from the neighbouring pole of the magnet, cause corresponding modifications in the distribution of the magnetic lines of force in the field passing through the coil. These variations in the lines of force give rise in the wire of the coil to induced currents of varied direction and strength, and these currents are by the line wire transmitted to the coil of the receiver.

The explanation of the phenomena which occur in the receiver of the Bell telephone given in the preceding pages (§ 17) is considered by some, if not as inexact, at least as insufficient. Instead of regarding the vibration of the diaphragm as due to magnetic attractions and repulsions of the magnetized bar only, there is an inclination on the part of French physicists to believe that the rapid magnetisations and demagnetisations in the bar produced by the induced currents give rise to molecular disturbances in the mass of the bar, that these disturbances are communicated to the diaphragm, and there cause oscillatory motions which finally manifest themselves in sonorous vibrations.

On measuring the currents developed in a Bell telephone they are considered much too feeble to account for the effects produced in the diaphragm of the receiver, if these effects were to be attributed to attractions pure and simple. This is simply a theoretical difficulty; but it is borne out by Ader's experiments (§ 27), who constructed telephones without a vibrating membrane and even without a magnet, and has obtained transmission of speech with magnets made from iron wire fixed to a small plate and placed in communication with a metallic mass, and, further, the experiments of Antoine Bréguet, who replaced Bell's thin membrane by plates of fifteen centimetres thickness, clearly indicate that molecular effects and magnetic attractions combine together to reproduce the sounds of the transmitter. In short, the actions and reactions at play in the telephone are less simple than was thought at first, and the theory of this beautiful instrument is far from being finally settled.

24. It has called forth the exercise of a considerable amount of ingenuity, of experiment and writing in France. Du Moncel, who studied it with great care, arrived at the following conclusions:[1] There exist in the Bell telephone several modes of reproduction of speech :—

1. The molecular vibrations of the magnetic core and its armature, consequent upon their alternate magnetisations and demagnetisations under the influence of undulatory currents.

2. The true electro-magnetic attractions of the mass of the diaphragm.

3. The reciprocal action of the spirals of the magnetising coil.

4. The mutual reaction between the coil and the magnetic bar.

5. The mechanical transmission of the vibrations of the electro-magnetic system by the various accessory parts constituting the telephonic apparatus.

[1] Du Moncel, "Le Téléphone," 4me édition.

Mercadier[1] considers the diaphragm to be animated by two movements, molecular and molar. The former are independent of form, like the resonance of a wall; the later are transversal, and act as a whole, like the skin of a drum. He replaced the iron diaphragm of the Bell telephone by a sheet of paper, cardboard, mica, glass, vulcanized india-rubber, zinc, aluminium, copper, etc., on which he sprinkled a small quantity of iron filings, and came to the conclusion that in the magnetic telephone, whether employed as transmitter or as receiver, the iron diaphragm never acts like a sonorous body vibrating in its entirety; it vibrates like a congregation of particles each gifted with independent movements.

There are, however, as Geraldy points out, certain facts proved by practical telephony which cannot be explained by this or any other theory. How is it that multipolar telephones (§32)—that is, instruments in which the diaphragm is opposed to several magnetic poles—do not of necessity show any superiority over unipolar ones? If all the particles of the diaphragm are in motion, if each of them contributes its share towards the reproduction of articulate vibration of speech, there would be a direct gain in utilizing all these movements, in employing all these molecules as modifiers of the magnetic field; in default of one rather large pole the employment of several poles would seem to be indicated; and yet we find that such is not the case. Further, why should several telephones, receiving the voice at the same time, and acting on the same line, not give a sensibly better result than a single one?

The views of Du Moncel and Mercadier have not

[1] La Lumière Électrique, 1886, p. 246.

received general acceptance, and we are content to believe that the diaphragm of a Bell telephone influenced by magnetic attractions and repulsions, acts as a simple sonorous body subject to harmonic displacements, and imparting these movements as sonorous vibrations to the surrounding air.

The theory of the telephone has given rise to much controversy, and it will probably continue to be an interesting subject for discussion. It, however, remains marvellous in its simplicity and astounding in its results.

The Microphone.

25. The true action of the microphone or carbon-transmitter is also very little understood; it introduces into a closed electric circuit, through which a current is flowing, a resistance which, varying exactly with the sonorous vibrations impinging upon it, causes the current to undulate in a way exactly analogous to the varying sound waves. This effect is generally assumed to be due to a greater or less intimacy of electrical contact between two semi-conducting surfaces abutting upon each other; but there is now very little doubt that it is due to the effects of heat generated by the passage of electricity between two points in imperfect contact, whose relative distance is variable. Carbon, according to Shelford Bidwell, is the best material for the purpose—first, because it is inoxidisable and infusible; secondly, because it is a poor conductor; and, thirdly, because it has the remarkable property of having its resistance lowered when it is heated—the reverse of metals.

Attempts have been made to apply mathematical analysis to the determination of the best form and arrangement of microphones, but at present the microphone defies mathematics. The fact is, that the conditions due to heat in the microphone, and to self-induction in the induction coil, are very complicated, and are not yet sufficiently understood to bring the phenomena they effect within the region of mathematical analysis.

Experiments made by Shelford Bidwell [1] show that the diminution of resistance of a microphonic contact is, under ordinary conditions, due not only to an increase of pressure, but also to an increase of current, which amplifies the effects independently of the diminution of resistance of the contact; and, further, it has been shown by Stroh [2] that the variations of current just mentioned must be attributed to variations of thickness of the thin layer of air intervening between the carbons.

The action of the microphone might then be explained in the following way:—By the passage of the current between two carbon points in loose contact heat is generated, the amount of which varies with the motion of the points, a variation of resistance in the circuit is the result; this variation of resistance causes a variation of current strength, and gives rise to undulatory currents.

The remark which has been made with regard to the theory of the telephone applies with equal force to that of the microphone—it is far from being established with any degree of certainty.

Hughes explained the variation of resistance by a variation of the *amount* of contact—that is to say, that in consequence of the change of position of the loose contact produced by the sonorous vibrations, a larger or

[1] Shelford Bidwell, "La Lumière Electrique," 17 March, 1883.

[2] Stroh, "Telegraphic Journal," 17 March, 1883.

smaller number of molecules take part in the transmission of current.

This explanation by no means excludes the theory stated above. It is at least conceivable that heat may assist the action of the sonorous vibrations. Professor Hughes favours the existence of little electric arcs at the points of contact. There are many phenomena, such as hissing and humming, that are clearly due to what is known as the Trevelyan effect, and therefore compatible with the heat hypothesis. In fact, with continuous use a transmitter becomes sensibly warm.

CHAPTER VI.

TELEPHONE RECEIVERS.

THE instruments which find a place in this chapter are all more or less modifications or imitations of the original Bell telephone, and we confine ourselves to the description of those which, either on account of a higher efficiency, or for reasons of novelty of construction, or from being in actual use, present features of interest.

26. An important modification of the Bell is—

Gower's Telephone.

The main difference between this instrument and Bell's consists in the form of the magnet, which, as will be seen by referring to Fig. 17, has a semicircular shape. The steel horseshoe magnet N O S, although small, is very powerful. Each pole supports a small oblong piece of iron, on which the coil is fixed. The whole is enclosed in a flat brass case, whose cover carries the diaphragm M. The thickness of this membrane is slightly greater than that of the Bell; it is fastened to the cover by a ring, and some screws placed in the circumference of the ring.

Gower employed, instead of the ordinary telephonic mouthpiece, flexible acoustic tubes, like those of a speaking-tube.

To call attention, Gower used a special arrangement represented separately by Fig. 17 in half natural size. It consists of a tube A bent at right angles, fastened to the membrane M. One end, T, of the tube faces the diaphragm, whilst the other opens into the telephone case;

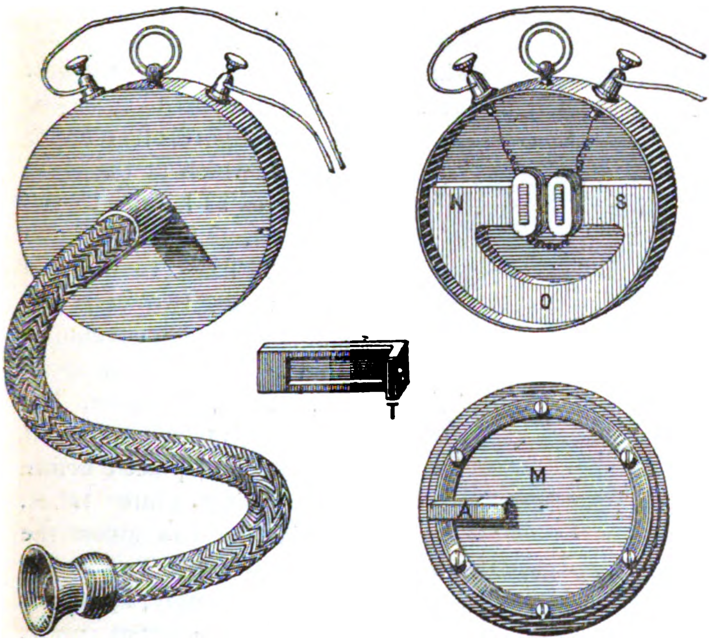


FIG. 17.

the tube contains a vibrating reed L. By blowing into the acoustic tube, the reed vibrates and communicates its vibration to the plate of the telephone much more effectually than could be done by shouting into the mouthpiece. These intense vibrations produce powerful induced currents, which give rise in the receiver to corresponding vibrations, and thus create a considerable noise. By adding a large resonant ear-trumpet to the apparatus, the sound can be heard at a distance of several feet. The addition on the membrane of the tube A in no way disturbs the clearness of transmission.

This is the receiver used by the British Post Office (§35).

Ader's Telephone.[1]

27. This telephonic receiver is extensively used in France, in Belgium, and in Austria. It consists, as will be seen from Fig. 18, of a circular magnet A, which at the same time serves as handle to the instrument. On the two cores, B B, fixed to the two magnet poles, two coils are wound, an arrangement similar to that in the preceding apparatus. Ader, however, has added to this telephone a soft iron ring, X X, placed before the vibrating plate M M, to which he has given the name of "over-exciter" (sur-excitateur). The object of this iron ring is to excite more strongly, by means of magnetic induction, the opposite magnet poles. The theory of this magnetic reaction was first stated by Du Moncel in 1878. He found that the more the mass of the armature of a magnet approached in magnitude the mass of the latter, the more powerful is their reciprocal induction, until, when the masses are equal, it reaches a maximum. If an iron

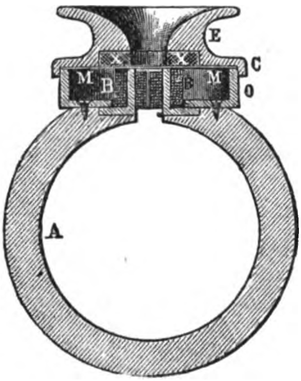


FIG. 18.

[1] Sieur, Étude sur la Téléphonie.

membrane be placed between the two masses it will be found in a strong magnetic field. This effect might be obtained by increasing the mass of the diaphragm itself, but the result would then be obtained at the expense of its vibrating capacity. The iron ring X X concentrates the lines of force perpendicular to the plane of the diaphragm instead of allowing them to be scattered. The variations produced in the magnetisation of the magnet by the induced currents consequently have a maximum effect on the vibrating plate, whose centre is placed in the strongest possible magnetic field perpendicularly to the lines of force. The telephone thus becomes more powerful and more sensitive to the extremely delicate inflections of the undulations constituting the timbre of the human voice. Ader's telephone receiver is certainly one of the most sensitive at present in use.

Kotyra's Telephone.[1]

28. The manufacturing of horse-shoe magnets is rather expensive, and their adjustment is difficult on account of the deformations which occur during the tempering of the steel. It is therefore desirable to find a means to render the construction of telephones employing horse-shoe magnets simple enough to allow of their being supplied at the same price as telephones with straight magnets. This problem Kotyra claims to have successfully solved.

The magnet M (Fig. 19) is formed of a large number of small thin plates of tempered steel of different length, cut out of the same bar and joined together so as to present the form of a horse-shoe. The pole pieces

[1] "La Lumière Électrique,' 1882, vol. vii., p. 527.

of the magnet consist of steel plates A A and N S of different length, which may be cut out of the same bar; the latter carry the iron cores of the electro-magnet coils B B_1 In this electro-magnetic system no piece has to be forged, and every plate being magnetised individually, a more energetic and more durable effect is said

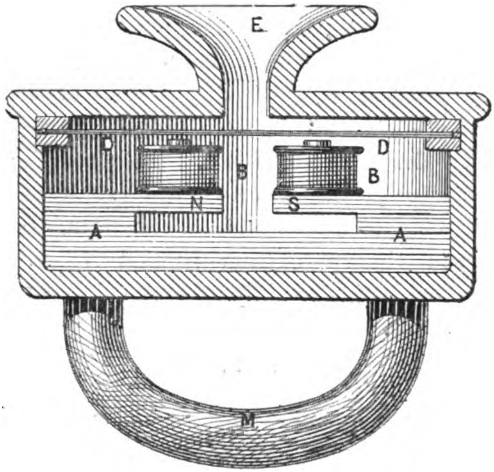


FIG. 19.

to be obtained than with a massive magnet made of one piece. The remainder of the apparatus, in which D is the diaphragm and E the mouthpiece, resembles an ordinary Bell.

D'Arsonval's Telephone.[1]

29. In telephones with two poles and two coils, such as have been described, the only really useful part is supposed to be the wire placed between the two poles; the part of the wire which is outside is almost com-

1 "La Lumière Électrique," 1882, vol. vii., p. 150.

pletely lost for induction, and simply creates a useless resistance, all the lines of force of the magnet being concentrated in the inter-polar space.

To subject the whole of the wire to induction, D'Arsonval has constructed an annular magnetic field, as in the Nicklès electro-magnets, by taking as centre one of the poles of the magnet, while the other pole surrounds it in the form of a circle. The induction coil being fixed to the central pole, all the parts of the wire are perpendicular to the direction of the lines of force, and consequently subjected to maximum induction.

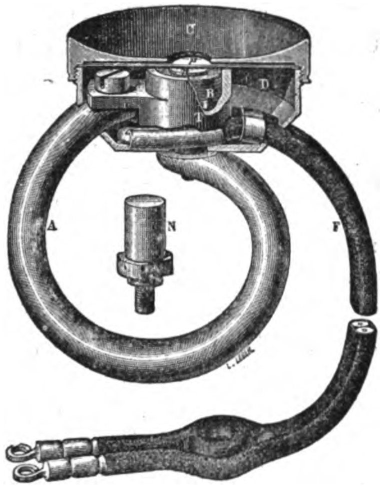


FIG. 20.

The magnet therefore consists of a spiral part A (Fig. 20), one extremity of which carries the central pole N, on which is placed the coil B; the other extremity carries an iron cylinder T surrounding on all sides the coil, which is thus, as it were, buried in a circular magnetic field of great intensity.

Finally, the box D, which carries the iron diaphragm, is fixed in the most simple and most solid fashion without requiring any screws; it is simply squeezed between the magnet and its core, represented separately at N.

The terminals have likewise been suppressed by a very simple system of fastening of the double conducting cable F.

In this form the complete instrument weighs 350 grammes (less than one pound), and gives excellent effects considering its slight weight.

Siemens' Telephone.[1]

30. This instrument is the receiver chiefly used in Germany; it is represented in Figs. 21 and 22.

On the horse-shoe magnet *m m* two steel polar pieces *s s*, are fastened by means of screws. The polar pieces carry the small oblong soft iron cores *u u*, which are wound with fine insulated copper wire.

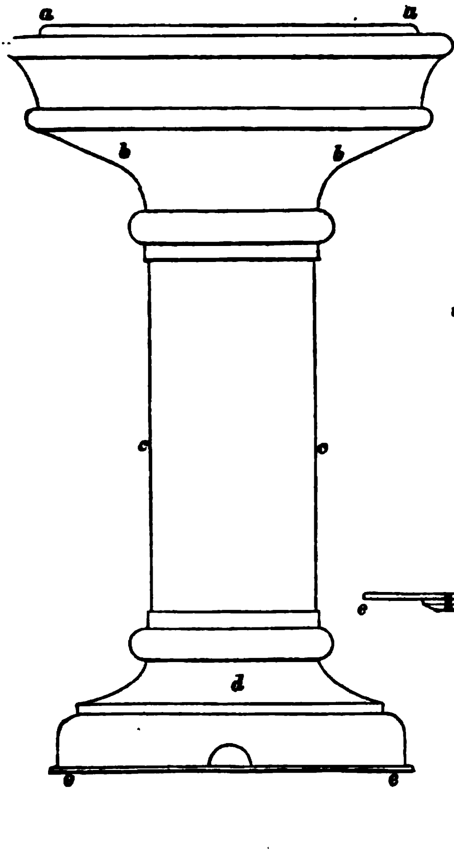
The horse-shoe magnet is joined to the plate *e e* by means of a screw *q*, which passes through the iron plate *e e*, through a wooden block *i* fixed to the plate, and through a brass plug in the centre of the wooden block. When, therefore the screw is tightened, the magnet is lowered, whilst it is raised by the opposite action of the screw. Two small boards *h h* press on either side against the two extremities of the magnet, and serve for the reception of the wires *r r*, which are connected to the convolutions of the two coils *u u*. The wires *r r* end in two screws fastened to either side of the block *i*, and the line wires start from these screws. An iron stirrup *g g* for the suspension of the instrument is fastened to the plate *e e*.

The whole mechanism is placed in a cylindrical tube of sheet iron *c c* (Fig. 22) in such a manner that *e e* forms the foundation plate of the apparatus.

The tube carries a top piece *b b*, and is above *b* closed

[1] Grawinkel, "Telephonie and Mikrophonie," p. 73.

in the interior by means of a round piece of sheet iron. The apparatus terminates in a conical mouthpiece *a a*



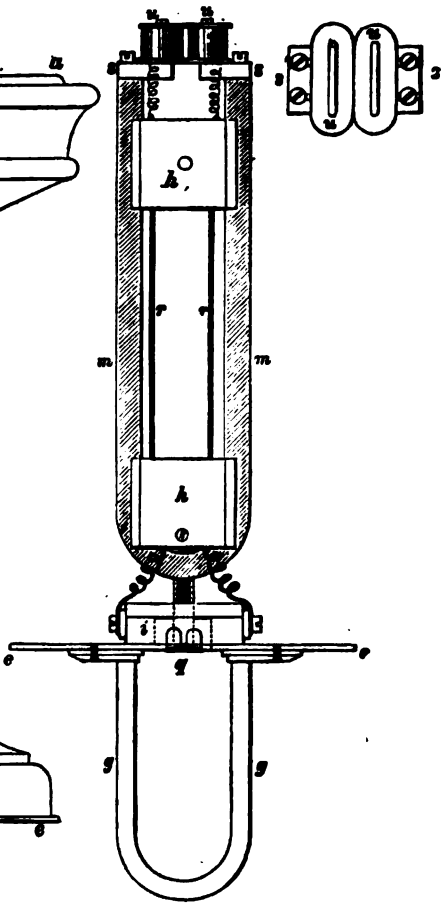


FIG. 22. FIG. 21.

of polished wood, in the centre of which is a round opening lined with brass.

The distance of the magnet from the membrane is regulated by means of the screw *q*, an arrangement which has been adopted in a number of other telephones.

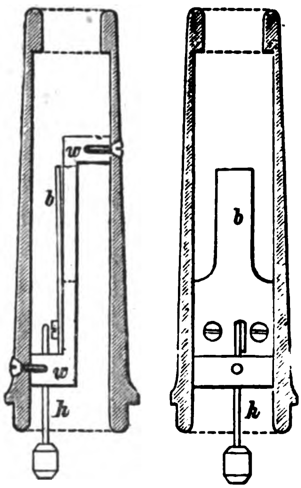


FIG. 23.

Siemens' apparatus, like the three preceding ones, differs from Bell's latest pattern only in the form of the magnet which it employs. The straight unipolar magnet has been replaced by one of the shape of a horse-shoe, and also the iron membrane is larger and stronger than that of the Bell instrument.[1]

The call is effected by a small whistle or reed, which is blown before the diaphragm of the transmitter, and produces a shrill tone in the receiver more than sufficient for the purpose.

The whistle (Fig. 23) consists of a conical tube of hardened indiarubber, in the interior of which an angular metallic piece *w w* is fastened by means of screws. A vibrating reed *b* is fixed at one end to the piece *w w*, and free to vibrate at the upper end. The lower part of the angle *w w* is perforated, and in the perforation plays a rod *h* provided with a small clapper.

On blowing into the whistle, which is fastened to the top of the apparatus, a sound like that of a penny-trumpet is produced; the clapper which touches the iron membrane by its up and down strokes strengthens

[1] Bell's original telephone contained a horseshoe magnet (Fig. 7, § 15).

the vibrations of the latter, so that a shrill loud tone in the receiver is the result.

Neumayer's Telephone.[1]

31. This instrument is used for the Bavarian telephonic service, and constitutes one of the most successful modifications of the original Bell. The magnet (Fig. 24) *m m* consists of five cylindrical rods of best hardened steel. The pole opposed to the diaphragm is formed in the following way. It has been explained in § 12, that by the introduction of a bundle of soft iron wire into the core of an electro-magnet, the inductive action of the coil is considerably increased. Neumayer, therefore, joins pieces of very fine iron wire (wire as used for wiring flowers), 3 centimetres in length, into a bundle, which he solders into a cylinder of thin brass. The upper half of the bundle is pushed into the coil, whilst the lower half joins the steel magnets as closely as possible. The steel rods are kept in position by a brass ring, *f*. In order to render the variations of distance between the pole and the membrane arising from variations of temperature as small as possible, and thus to dispense with a special regulation of the receiver, the brass cylinder surrounding the bundle of wires is screwed to the brass case,

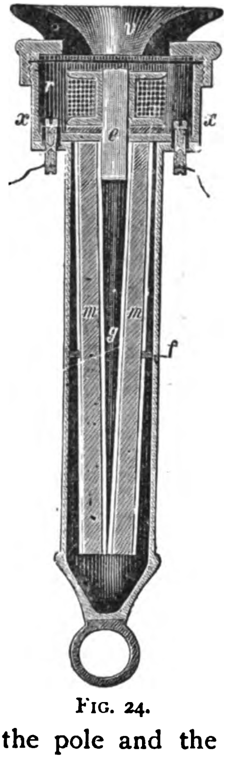


FIG. 24.

[1] "Electrotechnische Zeitschrift," 1884, No. viii., p. 339 (Fig. 7, § 51).

and the distance of the magnet from the membrane is thus rendered independent of the variations of length of the steel rods. The latter are surrounded by a wooden mantle, which is fastened to the bottom of the brass case. All the visible metallic parts are nickel-plated. The membrane is ·3 mm. thick, and rests with its rim of 2 mm. width on the edge of the metal case. It is kept in position in the usual manner by the vulcanite mouthpiece *v*, which is screwed on to the top of the case. The coil is wound with copper wire of ·11 mm., and has a resistance of about 100 ohms.

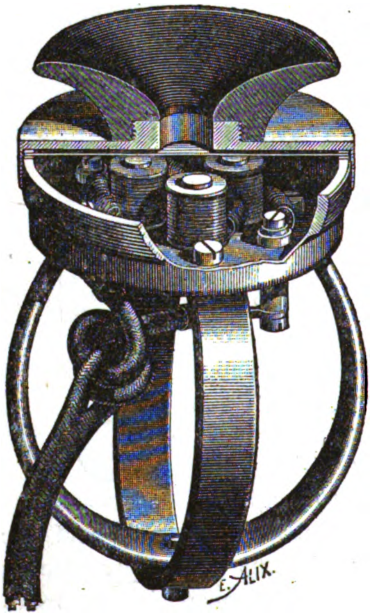


FIG. 25.

Goloubitzky's Telephone.[1]

32. Starting from the fact that several telephones placed at the receiving station can simultaneously reproduce speech without any sensible loss of sound in each of them, Goloubitzky thought that, by converting these several telephones into a single one, an apparatus might be obtained which would produce more intense sounds.[2] A further step in the same direction led him to the conclusion that several magnets

1 "La Lumière Electrique," vol. vii., p. 503, 1882.

2 The late G. W. Phelps had done the same thing in America in 1878.

acting at the same time on the same diaphragm would fulfil the same purpose, provided that the vibrations produced were concordant. These considerations resulted in the construction of the apparatus shown in Fig. 25. The poles of two horse-shoe magnets crossing each other at right angles are placed opposite the diaphragm, in the annular region corresponding to the centres of vibration; the four poles of the two magnets form the four angles of a perfect square, two poles of the same name being placed alongside one another. The diaphragm is separated from the cylindrical box of the telephone by a small copper ring surrounding the border. It is stretched and held at a convenient distance from the four magnetic poles by the cover carrying the telephonic mouthpiece. If a hollow sound is produced by tapping on the diaphragm through the opening of the mouthpiece, the adjustment is complete. The electro-magnet coils are first of all connected so as to correspond to the two different poles of the same magnet, and the two pairs of coils are subsequently joined for tension.

Böttcher's Telephone.[1]

33. This magnetic telephone was exhibited at Vienna in 1883. It acts both as transmitter and receiver. It consists (Fig. 26) of two horse-shoe magnets A M A, joined by their poles of the same name, and suspended between the elastic bottom of the case and the membrane by elastic wire loops in such a way that they can be regulated by two fine screws. In order to obtain rapid and thorough changes of magnetisation, each of the two pole pieces consists of three

1 "Bericht über die Internationale Electrische Ausstellung," Wien, 1883, p. 254.

separate iron rods P, which are surrounded by the two coils J. Above these iron cores lies the iron membrane *m*, at a distance of ½ mm. On speaking into the telephone through the tube T, not only the membrane but the suspended magnets are thrown into vibration, and

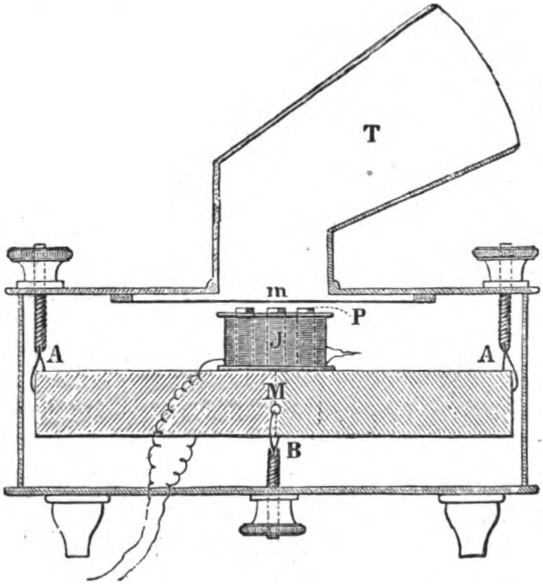


FIG. 26.

the telephonic effect is thereby considerably strengthened. The metallic telephone case rests on feet; a funnel-shaped mouthpiece T is placed above the membrane.

The Bell Receiver of the Swiss Telephone Administration.

34. By continuous improvements and careful workmanship this instrument is said to have been brought

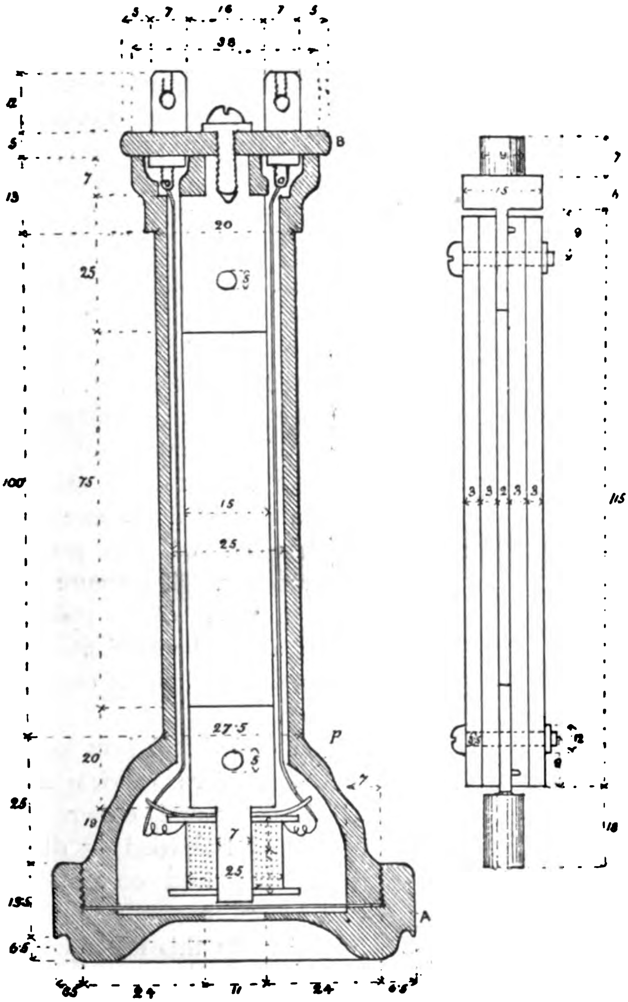


FIG. 27.

to a state of perfection which is not surpassed by any other Bell receiver now in use.

Fig. 27 represents a section through the receiver, and a side view of the compound magnet. The whole apparatus is enclosed in a polished ebonite case whose thickness is at least 2¼ mm. all over. The mouthpiece A being screwed on the case keeps the membrane in firm position in its whole circumference. This latter has a diameter of 57 mm., and a thickness of ¼ mm.; it consists of soft sheet-iron, and is coated with a thin layer of varnish.

The magnet is a compound one consisting of 4 laminæ of 115 mm. length; its breadth is 15 mm. and its thickness 14 mm.; it is made of the best magnetised steel, and can carry a weight of 400 grammes.

Two pole-pieces, shown in Fig. 28, of very soft iron and forged in one piece, are screwed on the poles of the magnet. To secure their rigid fixture, each pole-piece carries a pin S, which fits into a corresponding hole of one of the laminæ.

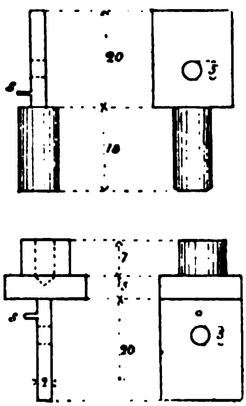


FIG. 28.

The cylindrical iron core of the pole-piece carries a coil which is wound either on a bobbin of boxwood or directly round the iron core, and in that case carefully insulated from it. In this latter case the iron core carries two discs of ebonite or vulcanised fibre of 2 mm. thickness. The coil has a maximum resistance of 100 ohms; the diameter of the bare wire is ·15 mm. No. 38 B. W. G. There are 2,500 convolutions on the coil.

Two cotton-wound wires of 1 mm. diameter are soldered to the coil, and thence lead to the terminals which are fixed upon the disc B (Fig. 27).

The disc B is screwed on to the magnet.

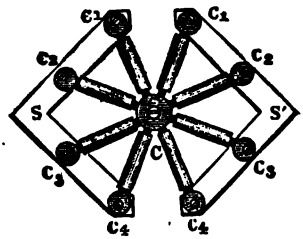
These are a few out of a great many modifications that have been introduced in the Bell receiver in different countries; but for real simplicity, efficiency, and economy, it is very doubtful if the original form designed by Bell and described in § 16 has been improved upon. The Gower may be louder, the Ader more sensitive, but 99 per cent. of the instruments in use at the present time are pure Bell telephones, and retain their pre-eminence against all comers.

CHAPTER VII.

CARBON TRANSMITTERS.

The Gower-Bell Transmitter.

35. This transmitter, which is shown in Fig. 29, consists of eight carbon pencils or cylinders C, supported between eight outside carbon blocks, C_1 C_2 C_3 C_4, and one central block, the whole being fixed beneath the diaphragm, which is a simple deal board about 22 cm. × 12·7 cm. × ·3 cm., fixed as in Fig. 34, p. 68.



¼ real size.

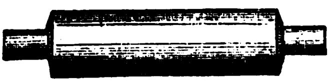


FIG. 29.

The carbon pencils, one of which is shown full size (Fig. 29), are connected together, in two sets of four, by means of thin copper strips, S S′. The battery current, on its way to the primary wire of the induction coil, enters one set of carbons through four of the eccentric blocks, passes through the centre block, and leaves by the second group of pencils.

The diaphragm is protected by a teak board, and is furnished with a porcelain mouthpiece.

The receiving telephone is placed in the box of the transmitter itself, but on a separate base. It consists

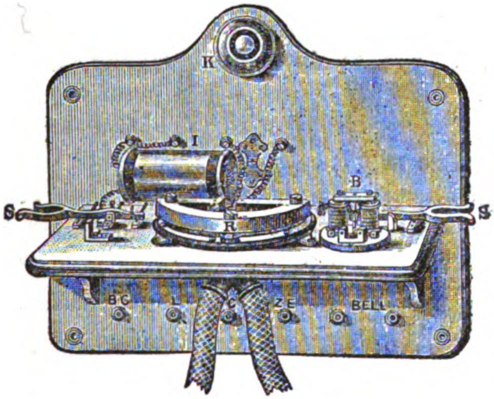


FIG. 30.

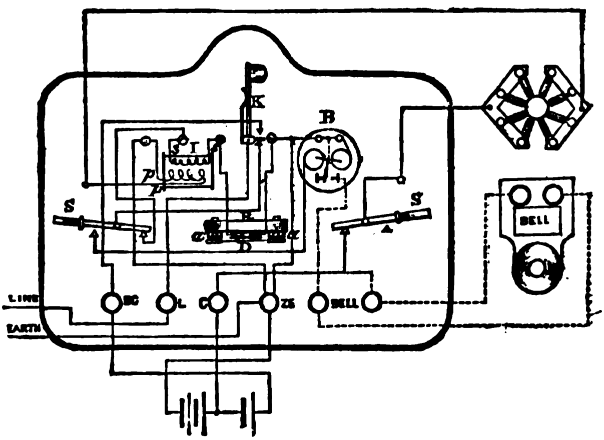


FIG. 31.

of a permanent magnet having its poles bent round and brought as near as possible to the middle of the diaphragm. The two small bobbins with soft iron cores are fixed upon the permanent magnet, one being attached to each pole, as shown in Fig. 17, § 26.

The general arrangement of the instrument is shown by Fig. 30. Fig. 31 shows the complete electrical connections. The resistance of the primary wire of the induction coil is ·5 ohm., and that of the secondary wire 250 ohms. Two No. 1 Leclanché cells are used for speaking. The resistance of the receiver is 200 ohms.

Ader's Transmitter.

36. The carbon cylinders are of the same form as

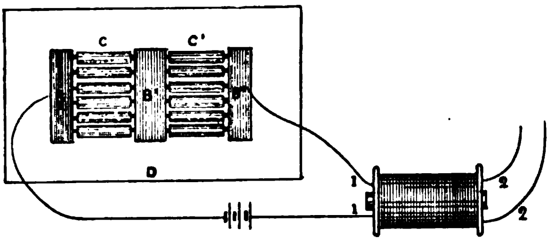


FIG. 32.

in the preceding one; but they are more numerous and arranged between three carbon blocks, B B′ B″ (Figs.

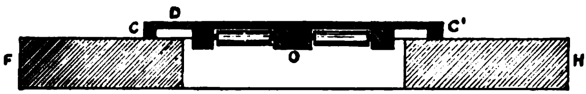


FIG. 33.

32 and 33). The battery current, on its way to the primary wire of the induction coil, enters through block

B, passes through the cylinders arranged at C and C′, and leaves through block B″.

The diaphragm D is a deal board, which is exposed like that of Gower-Bell, and allows of a conversation being carried on at some distance from the apparatus. The diaphragm is fastened to a caoutchouc frame C C′, which in its turn is glued to the board F H, through which there is a hole at O to allow a free space for the carbons.

The variations of contact between the carbon cylinders and the carbon blocks produce, as we have already pointed out, variations of current strength in the primary wire of the induction coil. These variations are effected in the following manner: When the vibrating diaphragm makes a downward movement, the blocks B B′ B″ follow this movement, whilst the cylinders C C′, through inherent inertia, have a tendency to remain in place, and this establishes loose contacts between the cylinders and the blocks. When, subsequently, the diaphragm executes a reverse upward motion, the blocks which follow the diaphragm press more closely against the cylinders, which still have a tendency to descend—hence a better contact between the cylinders and the carbon blocks.

Crossley's Transmitter.

37. The diaphragm of Crossley's apparatus (Figs. 34 and 35) is a very thin deal board D, having at the corners small cork pads L, which in their turn are glued to a board F H, in the centre of which is fastened the mouthpiece E.

Below the diaphragm (Fig. 34) are fastened four carbon blocks B B′ B″ B‴, between which four carbon cylinders C C′ C″ C‴ are arranged.

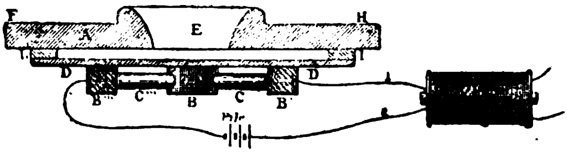


FIG. 34.

Fig. 35 represents the arrangement of each cylinder between two blocks. It will be seen that each extremity of the carbon cylinder C, of smaller diameter than that

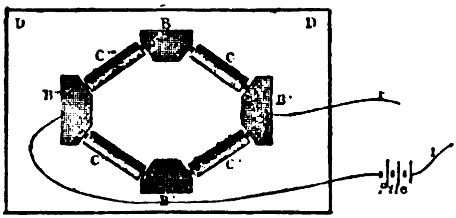


FIG. 35.

of the central part, rests, as in the former transmitter, on the lower ledge of an opening in the carbon blocks B B′.

Paul Bert and D'Arsonval's Transmitter.[1]

38. The arrangement of the carbons on the diaphragm of the transmitter (Fig. 36) is very similar to that of Hughes' microphone (§ 22), and differs from it only by the number of carbons and the mode of regulation.

The carbon blocks B B′ B″ have conical holes for the reception of the carbon pencils C C^1 C^2 C^3; the latter are surrounded by a covering F of sheet iron, and behind them

[1] Sieur, Etude sur la Téléphcnie.

is a horse-shoe magnet A, shown in section on the left of Fig. 36 and in dotted lines on the right. This magnet, which can easily be regulated by approaching it to or withdrawing it from the carbons by means of a screw, attracts the iron covering of the carbons in such a manner that, under the influence of the vibrations of the diaphragm D, their contacts with the blocks B B′ B′′ are modified without breaking, and produce the variations of resistance

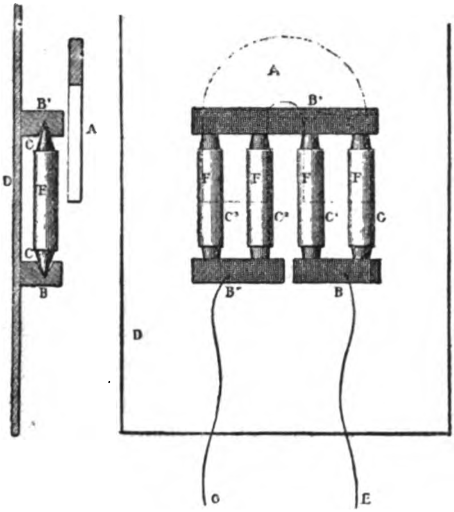


FIG. 36.

and of current strength which have been already described. It will also be seen from the figure that the movable carbon cylinders are arranged, two for tension and two for quantity; the current entering through E passes to block B, and simultaneously through the cylinders C and C^1, thence through block B′, then simultaneously through the cylinders C^2 and C^3, and leaving through block B′′ completes its circuit through the primary wire of the induction coil, whose secondary wire is in connection with the line wire, as in the systems already described.

Blake's Transmitter.[1]

39. This apparatus is represented in Figs. 37 and 38. A small wooden frame H cut out in the middle, so as to form a mouthpiece *a*, carries on its reverse side an iron ring *r r* (Fig. 38), to which two pieces *b b* are screwed opposite each other. These two pieces are connected by the conducting rail *c*, which is kept in position, on the one hand by the brass plate *m*, and on the other hand by the screw *n*. Immediately behind the funnel-shaped mouthpiece *a* lies the iron diaphragm *e*. Between the diaphragm and the vertical rail *c*, which is bent at right angles in its upper part, is an interval of about 2 cm. At the extreme end of the shorter arm of rail *c*, an insulated piece fastened with screws carries a thin flexible steel spring *f* whose extremity, ending in a platinum contact, on one side presses against the diaphragm, whilst on the opposite side it presses against a small carbon disc *k* fastened to a small brass plate *p*. This plate *p* is fastened to the lower extremity of a flat spring *g*, whose upper end is fixed to the shorter arm of rail *c*. Spring *g*, which is coated with gum, and spring *f* are therefore in electrical connection only by means of the platinum

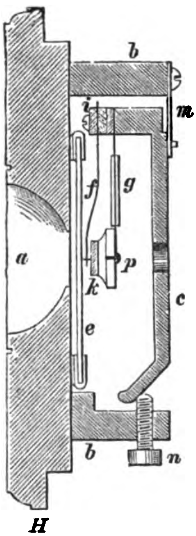


FIG. 37.

[1] Grawinkel, Téléphonie and Mikrophonie, p. 86.

contact, being separated at their upper end by the insulating piece *i*. The diaphragm *e* is contained in the india-

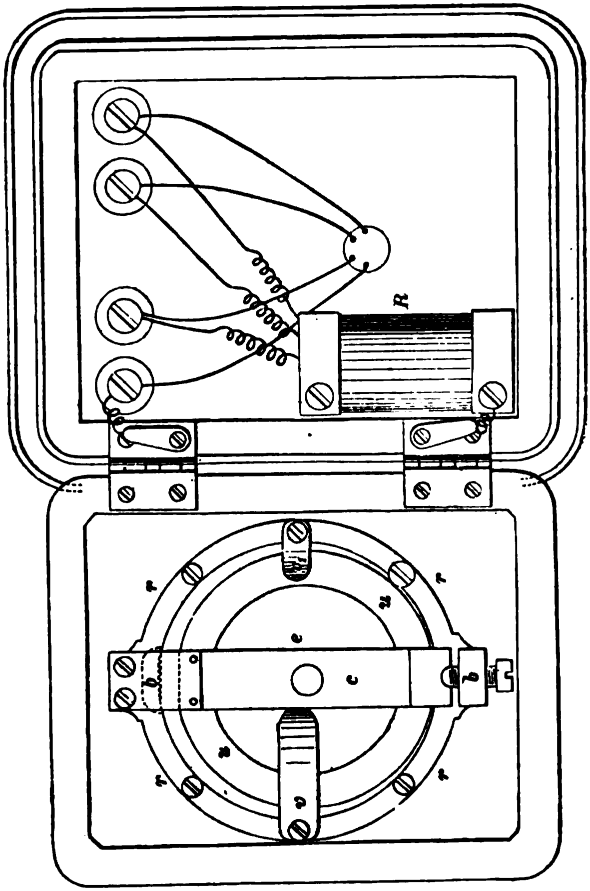


FIG. 38.

rubber ring *u* (Fig. 38), and is kept in position by the springs v and v_1, screwed on to the ring *r*. The frame H forms the door of a small case in which is placed the induction coil R (Fig. 38.) The current passes from one pole of the battery through the primary coil, over ring *r*, the upper piece *b*, brass plate *m*, the upper arm of rail *c*, spring *g*, brass plate *p*, carbon disc *k*, the platinum contact of spring *f*, and back to the other pole of the battery. The secondary coil is placed in the line circuit.

If the diaphragm *e* is thrown into vibration, these vibrations are transferred to spring *f*, so that the platinum contact presses more or less strongly against the carbon face of the plate *p*.

This transmitter is more extensively used than any other, and though it is by no means the best, it works so efficiently that it holds its own with great pertinacity against all rivals. Its articulation for short distances is very good, but when used for long distances its results are inferior to others (§ 71).

Maiche's Transmitter.[1]

40. A carbon block B (Fig. 39) is fixed to the centre of a very thin cork diaphragm D of 4 to 5 cm. diameter. Against the block B rests a small carbon cylinder C, attached to the lower extremity of a lever L, articulated at O, and whose other extremity is a screw provided with a globular screw-nut E, which serves for regulating the pressure of the contact of the carbons. Maiche places three, four, or five discs similarly arranged on the same wooden board, and covers the front of the board with a piece of cloth or serge.

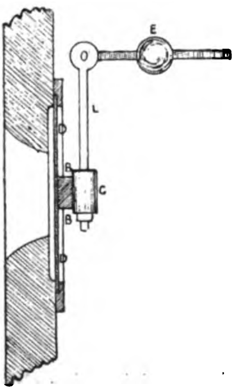


FIG. 39.

[1] Sieur, Etude sur la Téléphonie.

The contacts, as well as a corresponding number of induction coils, are, according to the conditions of resistance, placed in parallel or in series.

Locht-Labye's Transmittr.[1]

41. In all the transmitters described above, the diaphragm, formed of a thin metallic plate or a thin deal board, is held in a fixed position, either at each corner, on two opposite sides, or all round. In Locht-Labye's apparatus, however (Figs. 40 and 41), the little cork board L is simply fixed in its upper part by two very flexible spring-plates R R. On the lower part of the board is fixed a carbon disc C, against which a metallic finger B rests.

The contact between the carbon disc and the abutting finger closes the circuit of the battery passing through the primary wire of an induction coil, whose secondary wire is connected to line.

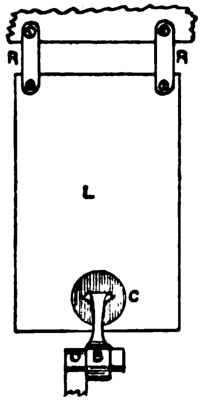


Fig. 40.

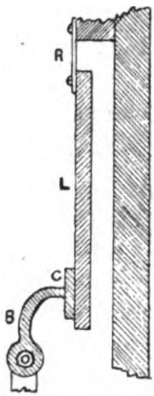


Fig. 41.

On speaking before the board L this latter vibrates, and its vibrations produce variations of resistance at the point of contact between the carbon disc C and the finger B.

The finger B is articulated at O, in such a way as to admit of adjustment of the apparatus, which consists in

[1] Sieur, Etude sur la Téléphonie.

pressing the finger against the carbon disc sufficiently close to prevent any breaking of contact during the vibrations communicated to the board L by the action of the voice.

The transmitter and the induction coil are placed in a box covered by a piece of woollen cloth, which slightly deadens the vibrations of the air, and thus prevents, to a certain extent, the breaking of contact.

Berliner's Transmitter.[1]

42. This instrument, in its crude form, was patented by Emil Berliner, of Boston, Mass., as early as 1877.

The apparatus may be considered as the type of that class of microphones which are called *pendulum-microphones*, that is to say, microphones which, as in Maiche (§ 40), have one of the contact pieces suspended like a pendulum.

In Fig. 42, which shows the instrument exhibited in Vienna in 1883, the contact is formed by a cylindrical piece of hard carbon *k*, rounded off at one extremity, and suspended to an articulated lever *t*. The contact piece *k* presses by its own weight uniformly against a plate of hard carbon *c*, which is fastened to the centre of a circular diaphragm P. This latter is, in order to insulate its vibrations, surrounded on its entire circumference by a indiarubber ring *n*. To damp down in the centre the vibrations of the diaphragm, a spring *f* coated with caoutchouc is inserted between it and the carbon plate. When the instrument is closed, spring *f* rests with its free metallic end against another spring *q*, and thereby

[1] "Bericht über die Internationale Electrische Ausstellung," Wien, 1883, p. 265.

makes connection with the wire of the primary coil *r*. At the same time, the diaphragm P is by the spring *f* pressed against the cast-iron cover of the microphone case. When the case is opened the diaphragm P is only fastened at the top by means of a metallic arm, which also carries the intermediate pieces for the carbon stud *k*.

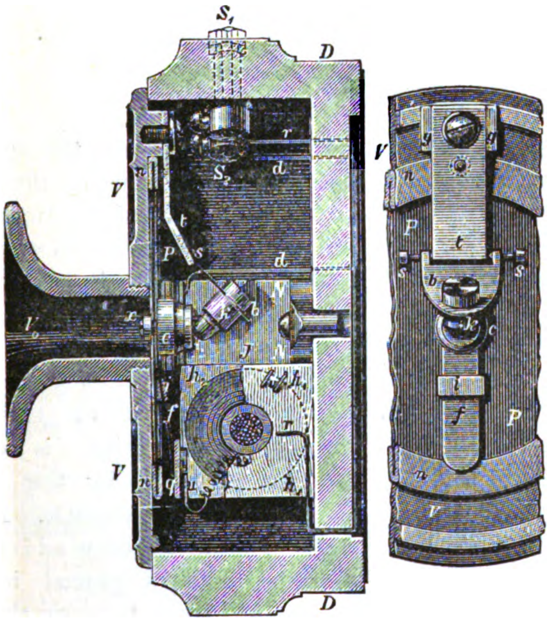


Fig. 42.

According to the conditions of resistance in the circuit lighter or heavier carbon studs are employed. The case of the transmitter has the shape of a cylindrical box, and is of wood with the exception of the cover. The current passes from terminal S_1 to the metallic piece which carries the lever *t*, thence through the movable carbon *k* to the fixed contact carbon *c*, and from there, by means of the two springs *f* and *q*, through the primary coil to the terminal S_1, and back to the battery. The wire of the secondary coil is connected to two exterior terminals, which are in communication with the line and return wires.

For long lines Berliner employs a special transmitter of similar construction, but with three contacts.

Burnley's Transmitter.[1]

43. The variations of contact between two carbon-electrodes *c* and *c′* (Fig. 43) are produced by the vibrations of the two membranes *m* and *m′*, which are equally affected by the sound emitted before the mouthpiece A. The closeness of contact of the two electrodes is determined by the regulating screw R. A pad of cotton wool is sometimes placed in the space between the diaphragms in order to damp down the abnormal vibrations of their internal surfaces without interfering with the effect of the sounds which strike the outside.

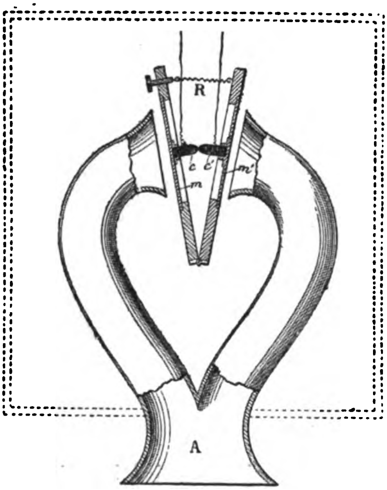


FIG. 43.

[1] "La Lumière Electrique," No. 5, 1886, p. 210.

The adjustment of the apparatus is effected by means of spring R, or by a greater or lesser inclination of the plane which supports one of the electrodes.

Wreden's Transmitter.[1]

44. This apparatus attracted a good deal of attention at the Vienna Electrical Exhibition by its great simplicity, combined with a high efficiency. It consists (Fig. 44) of a thin cork diaphragm T, which carries one of the carbon contacts K, whilst the other, K′, is pressed against it by a lever G H R. The regulation of the carbon contact is effected by the displacement of a weight G, as in Maiche (§ 40), screwed on to the extremity of the lever, or by screwing an additional weight on the lever; each instrument is provided with six additional weights, increasing from one decigramme to one gramme. The smaller the additional weight the looser is the contact and the more sensitive the microphone. The same effect is obtained by an approach of weight G towards the contacts. When once the highest degree of sensitiveness for certain individual conditions is reached, it remains constant and requires no subsequent adjustment. The current path is S K K′ R H S′ and back to the battery through the primary wire; L is the mouthpiece.

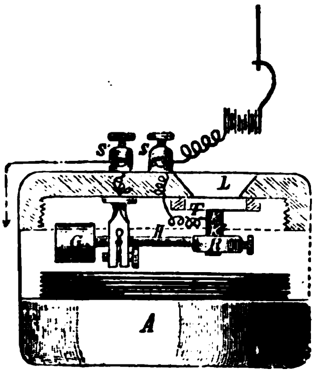


FIG. 44.

[1] "Bericht über die Electrische Ausstellung," Wien, 1883, p. 275.

Single as well as multiple-contact transmitters were exhibited at Vienna ; in the latter case the different contact levers (three, four, six, and twelve in number) were, according to the individual conditions of resistance, arranged either in series or in parallel. For the reproduction of orchestral music the parallel connection is especially favourable.

An apparatus of a higher order is shown in our figure, and consists of a box which is held in the hand when speaking, and has from one to twelve contact levers ; for diving operations this box is made water-tight and weighted with lead.

Ericsson's Transmitter.[1]

45. The instrument manufactured by L. M. Ericsson & Co. of Stockholm is shown in Figs. 45 and 46. It consists of a vertical sound funnel, which has a horizontal membrane *s* (Fig. 45) at its lower extremity. A carbon disc is fastened to the centre of the membrane, which, as in Blake's, makes contact with a platinum stud, carried by a metallic rod, by means of a spring *f*, which presses the rod upwards. A second similar carbon and platinum contact is made at the lower extremity. Both the spring and the rod have their guidance in the case *h*. The regulation of the contacts is effected by means of the micrometer screw *e*, whose guiding nut is seen at *m*. A magnetic telephone is used as receiver, and a polarised bell is used for calls.

1 "Bericht über die Electrische Ausstellung," Wien, 1883, p. 276.

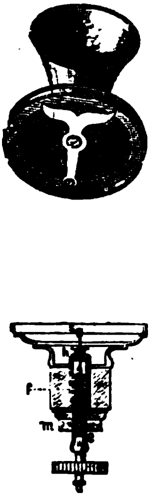


FIG. 45.

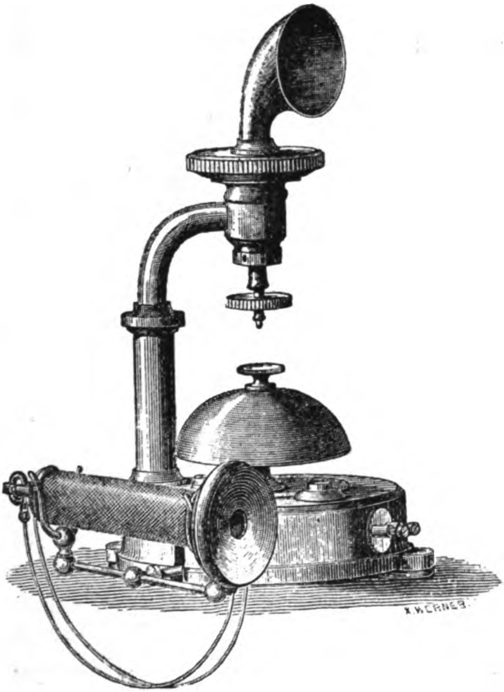


FIG. 46.

Freeman's Transmitter.[1]

46. With the object of strengthening the effects of the microphone, attempts have been made to multiply the variations of current by double induction coils and other double actions. A number of transmitters may

[1] "Journal Télégraphique," No. 1, 1887.

be classed under this category, and amongst them the above instrument occupies a conspicuous position.

It is, in its essential parts, a Blake type of transmitter: *a a* (Fig. 47) is the diaphragm which presses on the two-arm lever, *b c*, whose fixed centre is *d*. At *b* and *c* two platinum contacts press on the carbon lozenges *e* and *f*. The induction coil J is composed of three distinct wires. That in the centre *g*, which directly surrounds the core of soft iron wire, con-

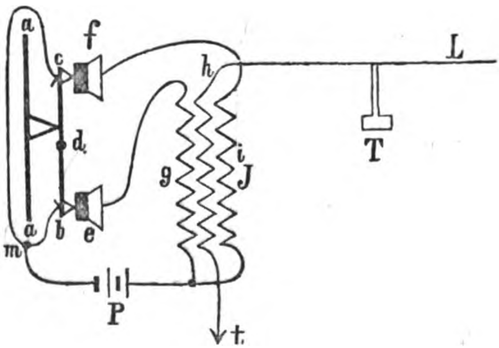


FIG. 47.

sists of a small number of windings of stout wire; it forms a part of the primary circuit. Then comes the secondary circuit *h*, consisting of a large number of windings of fine wire, and the external windings *i* are similar to those in the centre, forming the second part of the primary circuit. The coil is surrounded by a casing of soft iron, which produces on the spirals *i* the same effect as the core on the spirals *g*. The secondary wire *h* is in communication on the one hand with the line L, in which is placed the telephone T, and on the other hand with earth. The local battery P is placed in the circuit of the primary wires, that two independent circuits are formed, one being P *g e b m* P, the other P *i f c m* P. When the diaphragm vibrates, the resistances of these circuits are alternately augmented and diminished, the increase of the one corresponding to the decrease of the other. A weakening of current in *g* is therefore always accompanied by a strengthening in *i*, and *vice versâ*. These variations of current act in an inverse sense on the secondary circuit *h*, and an increased effect is the result.

47. Another successful application of the same principle is to be found in

The Transmitter of the Société Générale des Téléphones in Paris.

Fig. 48 shows a diagram of this instrument: *a a* is the diaphragm, *b* and *c* are two carbon blocks, one of which, *b*, is fixed direct on to the centre of the diaphragm, the other, *c*, being fastened to *b* by means of the non-conducting hoop *d*. The two carbons, although separated from one another, are thus

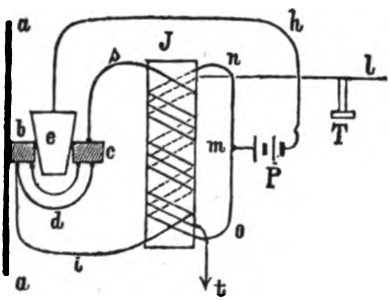


FIG. 48.

in rigid connection with the diaphragm, and follow the movements of the latter. Between the two carbons descends a metallic cone *e*, which, being suitably suspended, has a position independent of the carbons. It is clear that if the carbon receives an impulse from left to right, the pressure between *b* and *e* is augmented, while that between *c* and *e* is diminished. The contrary effects are produced if the centre of the diaphragm moves from right to left. The carbons and the metallic block are in communication with two different spirals of the induction coil J, and two primary circuits P *m n i b e h* P and P *m o s c e h* P are formed, through which the battery current flows in reverse directions. The effect on the secondary wire would therefore be *nil*, if the variations were the same in both the primary circuits; but since they are diametrically opposed to one another the effect is supposed to be, theoretically, doubled; *t* is earth, *l* the line, and T the telephone in circuit.

Theiler's Portable Telephone.[1]

48. The object of this instrument is to combine the transmitter with the receiver in such a manner that the two parts constitute a single, convenient, and easily portable instrument, which will transmit as well as receive speech when held to the ear, requiring no shifting from that position for transmitting, nor requiring the speaker to direct his voice towards any particular object.

The apparatus, as shown in Fig. 49, consists of a small drum or cylinder, N, of metal, or ebonite, closed at one end by the diaphragm A of the transmitter, and at the other end by the diaphragm B of the receiver. A screwed cover P, with a centre aperture *p*, and of the usual cup-shape, protects the receiver, and permits of the latter being held close to the ear.

[1] "Electrical Review," October 21st, 1887.

Into the cover-plate R of the opposite or transmitter diaphragm is inserted a tube or cone W, having a polished or smooth interior surface, and of such a shape that it collects and concentrates the sound waves from the speaker's voice upon the transmitter diaphragm without inconveniencing the speaker in any way, at the same time serving as a handle to the instrument.

The shape of this cone or tube is of great importance, and that in the figure has only been arrived at after many experiments.

It will be seen that the opening V of the cone is not placed in front or across the speaker's mouth when in use, but at the side. By this means inconvenience to the user, and the objectionable condensation of his breath upon the cone is avoided.

It will be further seen that the sound waves impinge only upon the outer curve of the cone, and would be conveyed to the diaphragm by that curve alone.

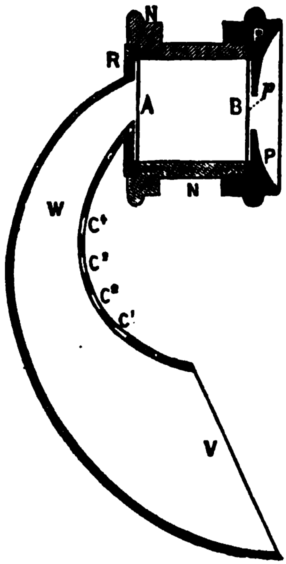


FIG. 49.

Therefore a row of holes, C^1 C^2 C^3 C^4, does not interfere with, but, on the contrary, assists the clear transmission of the sound waves along the cone W. Fig. 50 shows a transverse section of the combined transmitter and receiver, omitting, however, the tube or cone just described in Fig. 49. In order to get the receiver into a small space, Messrs. Theiler construct it with a circular permanent magnet O, one pole of which induces the iron core M, inserted into the coil L. The other pole induces the thin steel or iron diaphragm B. The transmitting part of the combination telephone is constructed as follows: —There is a very thin disc of steel or other highly elastic material, firmly clamped between the edge of the box N and the cover-plate R. To the centre of this diaphragm a thin carbon disc F is fastened, constituting one of the electrodes of the battery circuit. To the back of this diaphragm is glued a disc of felt, or other spongy material, with a hole *e* in its centre, which hole or chamber is filled with hard carbon granules, and closed by another thin steel or elastic disc *t*, to which a weight *d* is fixed, constituting the other electrode. A screw K traverses the weight *d*, and enters the chamber *e* to reduce the distance, and consequently the resistance between the two electrodes *d* and F.

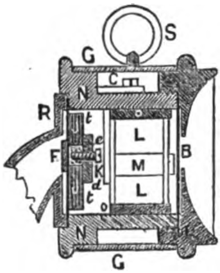


FIG. 50.

De Jongh's Transmitter.

49. The De Jongh transmitter is a very convenient and efficient form of carbon pencil transmitter.

It consists of a diaphragm of pine wood, 17 cm. × 10 cm. to which are affixed two series of carbon blocks, the surfaces of which are polished. Each set of blocks is connected together by means of a flexible wire, securely bound round each block. Behind the diaphragm, at a distance of half an inch, is placed a base board, into which are driven two rows of brass pins, bent to an angle of about 45°, and forming what is practically a series of inclined planes. Resting loosely upon these pins are four pencils, also of polished carbon. An indiarubber cushion separates the diaphragm from the base board. The whole is mounted in a suitable case, which is fixed vertically in any convenient position. The pencils press loosely against the carbon blocks fixed to the diaphragm and connect them together, and when the latter is spoken at the contacts are more or less affected, and the current correspondingly varied.

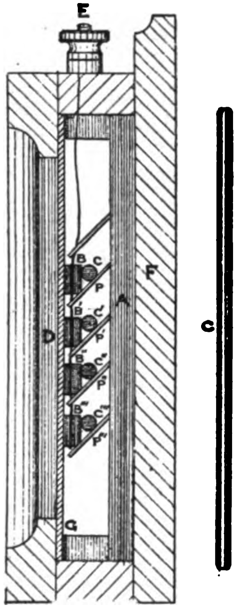


FIG. 51.

Fig. 51 shows the arrangement of the instrument in section.

A is the base of the transmitter, into which are driven the pins P P′ P′′ P′′′

B B′ B′′ B′′′ are one set of blocks, bound around each of which is the wire E.

C C′ C′′ C′′′ are the carbon pencils pressing against and connecting together the two series of blocks.

D is the diaphragm, which is clamped into position by the hinged front of the case F.

G is an indiarubber cushion between the diaphragm and the base of the instrument.

Mix and Genest's Microphone.[1]

50. This instrument, which has lately been adopted by

[1] "Industries," 19th August, 1887, and Rundschau für Electrotechnike, 1887.

the German Post Office, is represented in Figs. 52 and 53. The leading idea in the construction of this microphone was to avoid accidental derangement of the carbon contacts while retaining the advantages of a vertical position of the membrane. This is effected by a sort of brake, which prevents the carbon cylinders from resting against the lower points of the bore-holes of the carbon-holders; this secures the carbon contacts, and

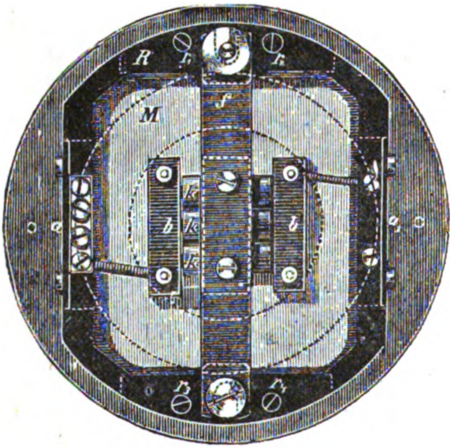


Fig. 52.

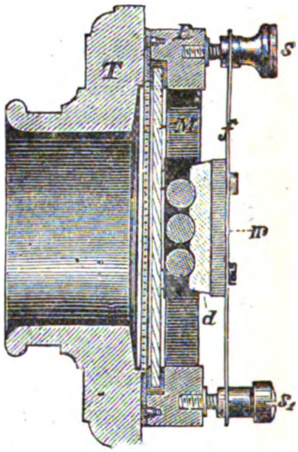


Fig. 53.

does away with the jarring noise to which microphones with vertical membranes are frequently exposed.

The mouthpiece T is screwed on to a cast-iron ring R, which is grooved, and carries in this groove the diaphragm M, of thin pine-wood, which is surrounded by an indiarubber band. Two clamps, *a a*, hold the diaphragm in position. Two carbon-holders *b b*, fastened to the diaphragm, carry in their bore-holes three carbon cylinders *k k k*. A spring *f* placed across the cylinders acts as a brake, and carries on its back a brass plate, between which and the carbon cylinders a soft material such as felt is inserted.

By means of the screws *s* and s_1 the cylinders *k k k* can be pushed slightly forward and pressed against the carbon-holders, so that the cylinders cannot revolve, and yet remain sufficiently movable.

Hunning's Transmitter.[1]

51. This microphone belongs to the class known as granular transmitters. It forms the base of a distinct type of its own, and has features of originality as well as of efficiency. It consists of a front vibrating diaphragm of platinum foil, of about 2¼ in. diameter, behind which, at a distance of from $\frac{1}{16}$ to $\frac{1}{8}$ inch, is a fixed platinum or carbon plate. The space intervening between the diaphragm and the fixed plate is loosely filled with granulated carbon (ordinary oven-made engine coke, powdered and sifted free from dust, is found to give the best results). The whole is mounted in a suitable case of wood, provided with a mouthpiece as shown in Fig. 54.

To secure the diaphragm against damage, a grid of fine wire gauze is inserted opposite the hole in the mouthpiece, and in front of the diaphragm.

The action of the instrument is as follows:—

When the platinum diaphragm is spoken at through the mouth-piece, its inner surface is brought more or less into contact with the coke granules, which causes them to press more closely upon each other. The

[1] British Patent, Specification No. 3,647, Sept. 16th, 1878.

resistance to the current which they offer is thus varied with the amplitude of the vibrations of the platinum foil, under the influence of the sound waves, and the current changes similarly.

Referring to Fig. 54, A A is a ring of metal securing the wire grid and platinum foil diaphragm around its circumference; B is the back contact plate; D is the diaphragm of platinum foil.

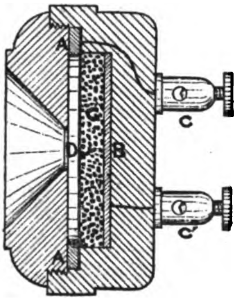


FIG. 54.

C C′ are the terminals for connecting the microphone to the battery and induction coil. They are attached respectively to the ring A and the plate B; G is the granulated carbon inserted between D and B.

52. Several important modifications of Hunning's transmitter were made by the late Charles Moseley, of Manchester. The platinum diaphragms were replaced by thin carbon discs, and they were placed in a wedge form, so as to secure uniform contact among the loose carbon particles. The terrible monopoly maintained by the holders of the patent rights in England prevented this transmitter from receiving the development it deserved. It was certainly the most powerful instrument tried in England.

Berliner's Universal Transmitter.

53. This is represented in Figs. 55 and 56. It has the following construction:

B is a wooden box with a screw cover B′. On the edge of B a brass ring M is fixed, which firmly holds the vibrating carbon plate D, and conveys the current to the latter. The carbon electrode C is fastened in the

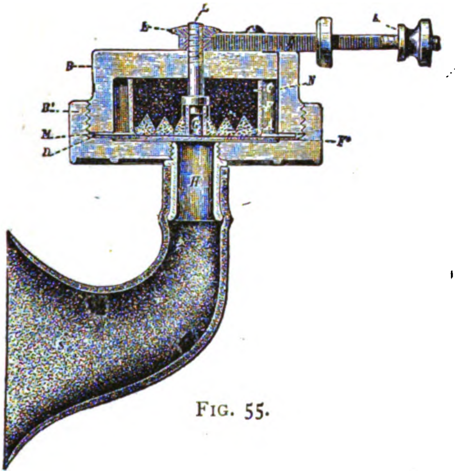


FIG. 55.

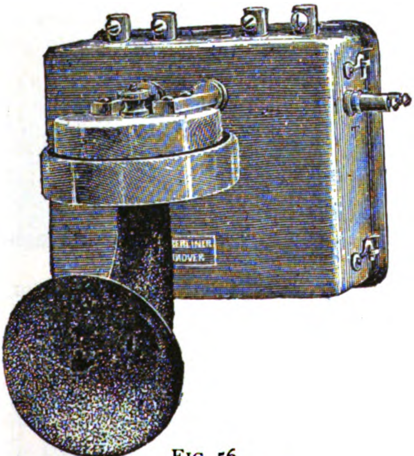


FIG. 56.

box by means of a pin L provided with a screw-nut E. Pin L is adjusted by the micrometer screw J K. At N is the second conducting wire, and beneath the pin L, which passes through the centre of the carbon electrode C, will be seen a conical plug which closely fits into the conical hole of the carbon electrode. This arrangement serves two objects: first of all for securing a good contact, and secondly for the reception of the small rubber tube G, whose opening abuts against the carbon membrane D, and thus damps down the vibrations of the latter.

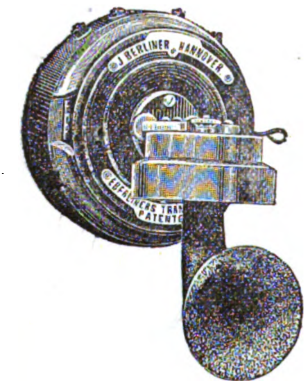


FIG. 57.

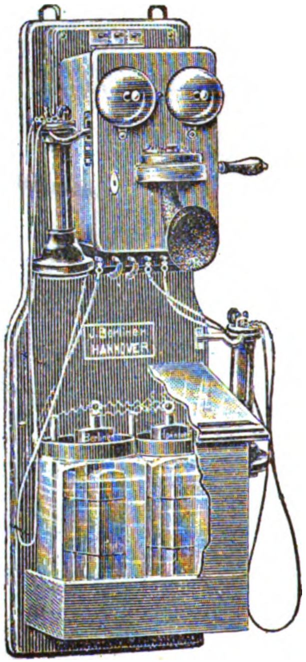


FIG. 58.

The carbon electrode is enclosed in its entire circumference by a ring of felt F, whose lower rim likewise touches the membrane D. A closed space is thus formed between the carbon electrode, the felt ring, and the membrane, which serves for the reception of the conducting granules A, which constitute the microphonic contacts.

A cylindrical piece H is screwed on the cover B, and to it the mouthpiece S is fastened.

Fig. 57 shows how this new mode of construction can be adapted to the older type of transmitter, such as the common Berliner (§ 42), the Blake (§ 39), etc.

Fig. 58 shows a complete combination set used at a subscriber's house.

Hipp's Transmitter.[1]

54. This apparatus, two forms of which are represented by Figs. 59 and 60, was exhibited at the Vienna Electrical Exhibition in 1883.

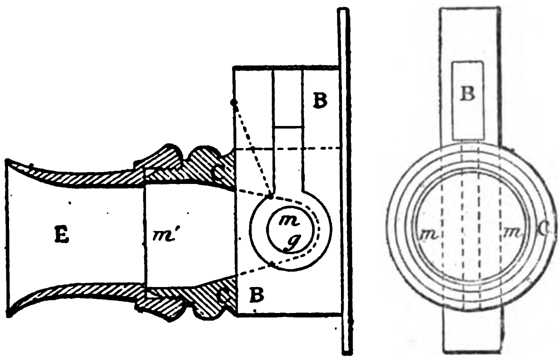


FIG. 59.

The essential part of the instrument is composed of a very flat cylindrical box B, (Figs. 59 and 60) made of a non-conducting material. An elastic membrane *m* forms both the cover and the bottom of the box. If this membrane is a non-conductor, two pieces of very thin platinum foil are glued to the interior side of the

[1] "La Lumière Electrique," No. 25, 1885, p. 129.

membrane. The resulting cavity is partly filled with a suitable conducting substance (carbon) in granular form (*g*). Connection with the battery circuit is made by means of two metallic wires soldered to the conducting part of the membranes.

The box thus arranged is placed in a cylindrical cavity C, in such a manner that the axis of the box is at right angles to the axis of cavity C. The latter is closed in

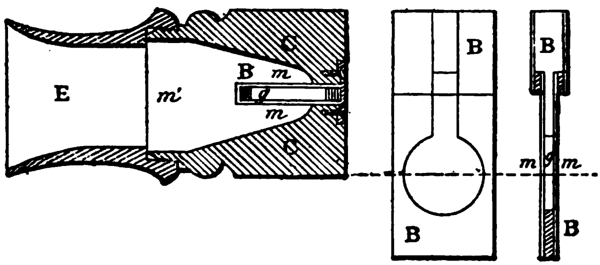


FIG. 60.

front by an elastic membrane *m'*, and over this membrane is fastened the mouthpiece E.

Boudet's Microphone.

55. The transmitter represented in Fig. 61 consists of a mouthpiece E attached to the extremity I, of a glass tube T of one centimetre diameter, which is itself fixed to a jointed support, so that the whole of the apparatus can be bent at any angle.

The mouthpiece carries an ebonite plate D of one millimetre thickness, to which is fastened a copper cylinder M^1 which projects into the glass tube. In this tube are placed six balls of hard carbon, of slightly smaller diameter than the tube, so as to allow them to move freely within the tube.

The microphone is completed by a second copper piece M^2 pressing against the bottom R of a hollow breach K, by the aid of a small spiral spring which is not represented in the figure. The screw V fixed to the stirrup Q

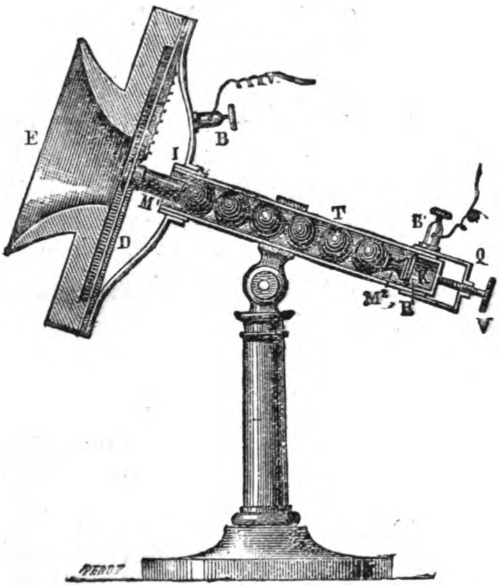


FIG. 61.

regulates the pressure of the piece M^2 against the balls. B and B are binding screws for battery and line wires The variations of resistance in the microphone equally affect all the contacts of the balls, because when speaking before the mouth-piece the vibrations are almost instantly transmitted through the series, as in the well-known experiment of the billiard balls.

CHAPTER VIII.

SPECIAL TELEPHONES.

WE propose in this chapter to describe some special forms of telephone which, though less practical than those hitherto illustrated, are not the less interesting.

We have to mention here in the first place an apparatus to which we have already alluded (§ 2) and which, from a historical point of view, presents a good deal of interest. This is

Reis's Telephone.

56. In 1860 Philipp Reis constructed this apparatus, by means of which a melody produced in a certain place could be transmitted to a great distance. The instrument is represented in Figs. 62 and 63, and consists of a transmitter and a receiver.

At the station where the tune is played a large tube T, leading into the box K, receives the vibrations of the air produced by the musical instrument. The box collects and strengthens the sound. In its upper part a membrane *m* is stretched which vibrates in unison with the vibrations it receives. These movements cause makes and breaks in an electric current. Let us suppose a battery, one of whose poles is to earth, connected by the other pole to the screw marked 2 in Fig. 62; from thence a metallic conductor, formed of a thin copper strip *i*, and connected with a platinum disc *o*, conveys the current to a point opposite the lever *a b c*. Each time the membrane *m* is raised, the point will touch the disc, and a current will be established; on the other hand, we get an interruption of current when the membrane returns to its state of rest. From the screw 1 (Fig. 62) starts the wire which connects the transmitter with screw 3 of the receiver (Fig. 63). The latter consists

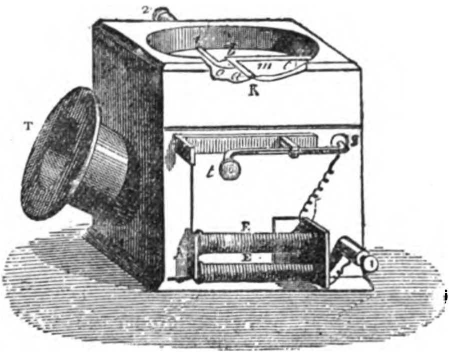


FIG. 62.

of an iron rod *d d*, surrounded by a spiral, *g*, of insulated copper wire; one of the extremities of the wire is connected with the screw 3, and the other with earth, by means of screw 4, thus completing the battery circuit.

Rod *d d* is about the size of a knitting needle; coil *g* consisting of the copper spiral, and the rod stands on a hollow box B, made of very thin wood; a cover D fits over the coil. The whole of this arrangement is intended to strengthen the vibrations which produce the successive interruptions of the current. The principle is the same as in a piano, where the intensity of the notes is increased by the resonance of the case.

It is a remarkable fact that the vibrations of the rod *d d* are exactly synchronous with those of the membrane *m*, and consequently with those of the instrument playing the tune. Not only is time kept, but also the tune; two of the factors which constitute melody, pitch, and are faithfully reproduced. Timbre only is wanting.

To complete the description, we have to add that both

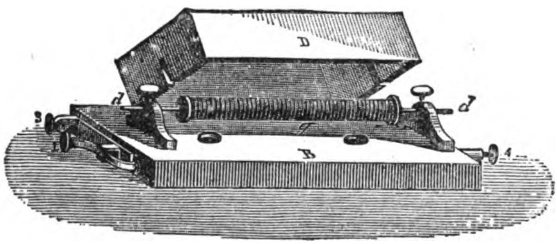


FIG. 63.

the transmitter and receiver are provided with a Morse key *t*, *s*, and a receiver E E for calling purposes.

The form to be given to the box K is an important factor in the construction of this telephone; it has been found most advantageous to make the sides of curved boards, and the efficiency of the receiver has been further improved by introducing several iron rods into the coil; the sound, which was in the first instance muffled, has acquired a more pleasing timbre. There can be no doubt, as we have already stated in the introduction, that Reis's instrument can and did reproduce articulate speech before Bell ever thought of his telephone; but it is one thing to make a great discovery, and quite another thing to make it commercially useful.

The Hand as Telephonic Receiver.

57. In pursuing his experiments on the transmission of musical sounds, Elisha Gray was accidentally led to construct a telephone in which the hand of the operator acted as a receiver. The phenomenon was first observed by Gray on the zinc lining of a bath, and the following is the author's description of the experiment and the apparatus to which it led[1] :—

"My nephew was playing with a small induction coil, and, according to his expression, was giving shocks to amuse the little children. He had connected one of the extremities of the induced circuit with the zinc lining of an empty bath. Holding with his left hand the other extremity of the coil, he touched the zinc with his right hand. As he was thus establishing contact, his hand was for a short time sliding along the edge of the bath. At that moment I heard a sound issuing from beneath his hand at the point of contact. This sound seemed to me of the same pitch and the same quality as that of the interrupter or vibrating electrotone of the apparatus which I heard likewise.

"Immediately I took the electrode into my hand, and on repeating the operation, I found, to my great surprise, that by rubbing hard and fast, I produced a clearer sound than that of the interrupter.

"Following up the idea suggested by the experiment

[1] G. B. Prescott: "The Speaking Telephone," p. 450.

of the bath, I constructed several apparatus with metallic plates for the reception of a sound by means of manual friction. An easy method for obtaining this result is the following:—

"The instrument has a metal stand of sufficient weight to keep it in position while being manipulated. Upon the stand a horizontal shaft is mounted in bearings, upon one end of which is a crank, with a handle made of some insulating material. Upon the other end is centred a thin cylindrical sounding box, made of wood, the face of which is covered with a cap made of thin metal, spun into a convex form to give it firmness. This box has an opening in the centre to increase its sonorous qualities. The metal cap is electrically connected to the metal stand by means of a wire.

"If the operator connects the cap through the stand to the ground, and, taking hold of the end of the line with one hand, presses the finger against the cap which he revolves by means of the crank with the other hand, the tune that is being played at the other end of the line becomes distinctly audible, and may be heard through a large audience room. If the conditions are all perfect, the faster the plate is revolved the louder will be the music, and the slower the motion the softer it will become. When the motion stops the sound entirely ceases." The effect depends on the variation in the intensity of the friction between the skin and the metal, due to the passage of currents—an effect discovered by Edison, and applied in his electromotograph.

Edison's Electromotograph.

58. If we soak a sheet of blotting paper in a saturated solution of caustic potash, and place it on a metallic

plate connected with the positive pole of a battery composed of two or three Leclanché cells, and then pass a piece of platinum foil, about one centimetre wide, over the surface of the paper, exercising a certain pressure on the foil, a resistance to the sliding motion will be felt, owing to the friction of the foil against the paper, which possesses a certain roughness of surface. If the platinum foil, while sliding over the paper, is connected with the negative pole of the battery, the resistance to the sliding will be diminished to a very great extent when the current flows; the electric current, therefore, has the effect of smoothing or lubricating, as it were, the rough surface of the paper. This effect of the electric current is proportionate to the current; it commences and ceases with it, and is so sensitive that the feeblest currents, those, for instance, which have no sensible effect upon an electro-magnet, are rendered quite perceptible.

In the instrument shown in Fig. 64, a thin diaphragm of mica, eight to nine centimetres in diameter, carries in its centre a strip of platinum C, which presses against the cylinder A with a constant pressure, due to the spring S and regulated by the screw E.

The cylinder A is made of chalk, and sometimes of a paste consisting of lime, caustic potash, and a small quantity of mercuric acetate. When of chalk, it is moistened with an easily decomposable electrolyte like potassic iodide. This plate acts the part of the paper soaked in potash in the preceding experiment. The cylinder turns with a regular motion by means of a system of multiplying wheels, and of the handle W. This system is replaced by a clockwork movement in more recent apparatus.

59. The electric current coming from the transmitter arrives by the support H, traverses the cylinder A coated with the paste, the platinum strip C, and leaves by the wire D to earth. By turning the cylinder A in the direction of the hands of a watch, by the handle W, the friction between the strip C and the surface of the

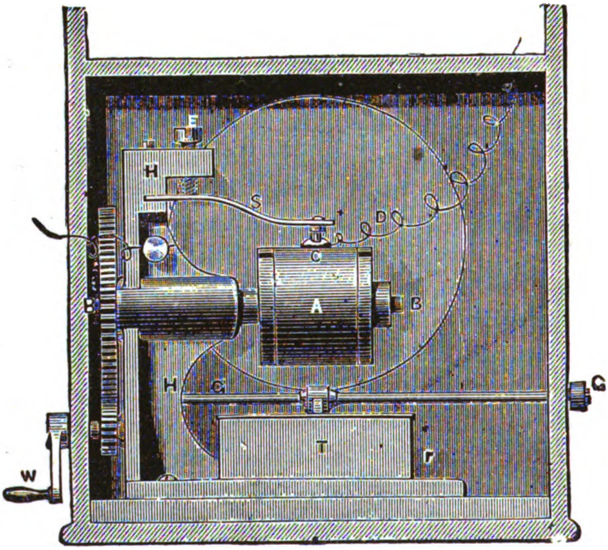


FIG. 64.

cylinder A produces traction on the strip C. The mica disc, on account of its elasticity, will take up a certain position of equilibrium, which will depend on the traction of the strip C and, consequently, on the friction between A and C; and as each variation of the current which traverses A and C will produce a variation in the traction of strip C, this will cause a certain displacement of the mica disc, which will thus vibrate synchronously with the undulatory current, and, consequently, synchronously with the membrane of the transmitter. The vibratory motion of the mica disc is, therefore, not obtained directly by the electric current, but is produced mechanically by the rotation of the cylinder A. The current effects a reduction of the friction resulting in a variation of the sliding motion, which explains the great power of the apparatus.

On the other hand, the mica disc, possessing little inertia and considerable elasticity, effectually transmits the impulses received by the strip C. It need scarcely be mentioned that, when the handle is not turned, the telephone does not act.

Rotation may be effected in either direction. The platinum strip C acts, according to the conditions, either by pulling or pushing the mica disc. The substance with which the cylinder A is coated must always remain moist, and this result is obtained by raising, by means of C, from time to time a small roller immersed in a solution of caustic potash which is contained in the reservoir T.

The sounds emitted are very loud, and can be heard over a large hall. Hence this receiver is a great favourite with lecturers. Its articulation, however, is very indistinct.

Bréguet's Mercury Telephone.

60. Antoine Bréguet utilised electro-capillary forces and the electric currents produced by them. The phenomenon which led to the construction of this instrument is reversible; the transmitter and the receiver are, therefore, two identical apparatus.

The point of a capillary tube T (Fig. 65), containing mercury, plunges into a vessel V. This vessel is partly filled with mercury M′, and partly with acidulated water A; the capillary point does not reach the mercury, and dips only into the dilute acid.

Two platinum wires P and Q communicate respectively with the mercury in T and that in V.

If the two wires are connected with one another, the level of the mercury in the capillary tube will be

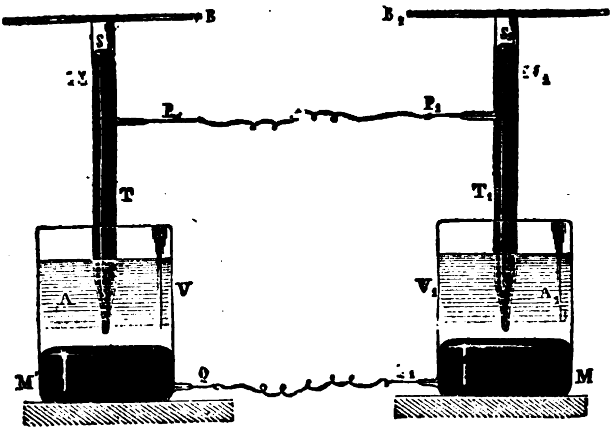


FIG. 65.

established at an invariable height. But if a battery is interpolated in the circuit of the platinum wires, the level will assume another position of equilibrium, depending on the potential difference. A definite level of the mercury will correspond to each difference of potential. Above the mercury in the tube is a layer of air S, whose pressure evidently varies every time the level of mercury itself varies.

The apparatus is reversible; that is to say, if by some modification of the pressure S the level of the mercury suffers displacement, a difference of the potential, or, in other words, an electro-motive force, will be established in the two conductors P and Q.

Let us now couple together two similar apparatus by connecting the wires P and P_1, Q and Q_1, as shown in Fig. 65. If pressure is exercised at S, an electro-motive force corresponding to that pressure will be produced in the circuit, and this electro-motive force will produce a change in the level of the mercury in the tube of the second apparatus, and consequently a change in the pressure at S_1.

On speaking above the tube T, the air contained in this tube enters into vibration. These vibrations are communicated to the mercury, which changes them into variations of electro-motive force, and these variations engender in the receiving apparatus exactly corresponding vibrations of the mass of air S_1; so that, if the ear be placed above the tube T_1, all the words pronounced into the tube T will be feebly heard.

The Photophone.

61. Experiments made by Mr. Willoughby Smith,[1] dating as far back as 1873, have shown that selenium is a body extremely sensitive to the influence of light, and that this influence manifests itself by modifying its electrical resistance.

Selenium was discovered in 1817 by Berzelius, and it occurs in two allotropic modifications. The vitreous modification is obtained by fusing selenium and suddenly cooling it; it is of dark brown colour, almost black in diffused light, and red and transparent when obtained

[1] "Journal of the Society of Telegraphic Engineers," vol. ii., p. 31.

in the form of very thin laminæ. The second modification, which is formed by fusion and subsequent gradual cooling, assumes a granular and crystalline form of metallic appearance. It is this latter modification which is a conductor of electricity at ordinary temperature, and which modifies its conductivity under the influence of light.

Professor W. G. Adams has shown[1] that when a ray of light falls upon a bar of selenium there is set up in that bar an electro-motive force which produces a current, the bar being, in fact, for the time, converted into a small battery. Bell and Sumner Tainter, after numerous experiments, succeeded in intensifying this sensitiveness, and have constructed an apparatus, to which they gave the name of *Photophone*, which enabled them to reproduce words at a distance by aid of luminous rays.

It has since been found that the radiations which produce the effect need not be luminous, and that radiant heat will give the same result. Mercadier proposed to apply to this apparatus the name *Radiophone*, and this term has been universally accepted; it means the conversion of radiant energy into sonorous vibrations.

Graham Bell and Sumner Tainter's Photophone.

62. The latest form of the apparatus is represented in Fig. 66. The transmitter, as will be seen, consists of a simple telephonic box B, provided with a mouthpiece and a vibrating membrane; this latter is made of silver-plated mica, thus forming a mirror, on which fall the rays of a powerful luminous source, such as those of electric light, or, better, of the sun. The

[1] Phil. Trans., 1874, vol. 167, p. 313.

bundle of luminous rays is reflected from the surface of the membrane, and, after passing through a lens R, which renders the component rays parallel, is directed on the receiver. This second part of the instrument is formed of a parabolic reflector C C, of silver-plated copper, about 70 centimetres in diameter, in the focus of which is fixed the selenium cell S, which communicates with the telephonic circuit.

63. Graham Bell has constructed *selenium cells* of the

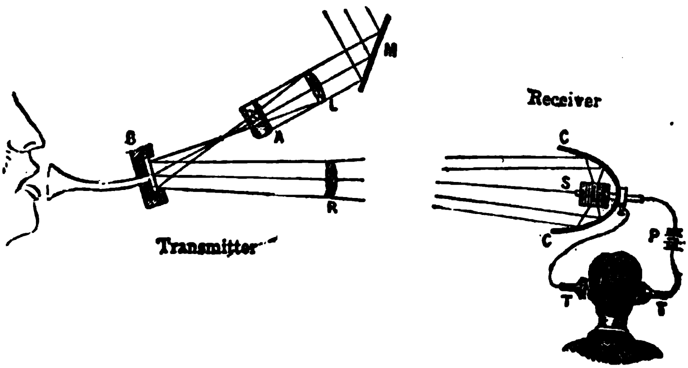


FIG. 66.

following form :—A number of brass discs are separated from each other by discs of mica of smaller diameter; the whole presents the appearance of a cylinder cut up on its surface by parallel circular grooves. These grooves are filled up with selenium, in the following way :— The cylinder is heated, and when hot enough a stick of selenium is rubbed over the surface. The selenium is then heated over a gas stove, and when it attains a certain temperature its beautiful reflecting surface becomes dimmed. A cloudiness gradually extends over it, somewhat like the film of moisture produced by breathing upon a cool mirror. This appearance gradually increases, and the whole surface is soon seen to be in the crystalline condition. The cell may then be taken off the stove and cooled in any suitable way.

Every alternate disc is connected to one wire of the circuit, and the remaining discs to the other wire. Every time that the light reflected by the parabolic mirror strikes the surface of the selenium, its electrical resistance is diminished, and this diminution is proportional to the luminous intensity. The luminous bundle, which, during the state of rest of the diaphragm, was transmitted without variation, is modified by the changes of form which the vibrations of the voice produce in the surface of the reflecting membrane at B. Hence we get, in the intensity of the luminous rays, variations which correspond to the variations of the sonorous waves, and produce, by the help of the selenium—that is to say, of a substance of variable resistance—variable currents in the telephonic circuit.

The photophone reproduces, with great clearness, musical sounds as well as articulate speech. Prof. Adams showed that tellurium, like selenium, changes its resistance under the influence of light, and a receiver constructed with it, although it gave no indication of its sensitiveness with a reflecting galvanometer, gave sounds in a telephone.

Radiophones.

64. Considering the extensive molecular motions produced by the action of intermittent rays of light on lampblack, Tainter thought that an analogous variation

would be produced in the passing current, and that it might be possible to replace selenium by lampblack in the receiver. Experiments confirmed this idea; Fig. 67 represents the lampblack element which has given the best results. A mirror is coated with a layer of silver, and the coating is removed so as to form a zigzag line, with two perfectly distinct parts, which have the appearance of two combs, the teeth of which fit into each other. Each comb is attached to a terminal, which enables the element to be inserted in an electric circuit.

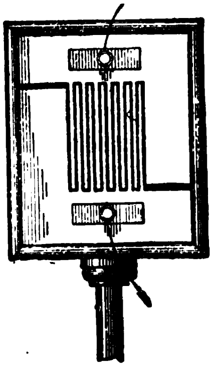


Fig. 67.

The surface is then blackened, so as to fill the whole interval between the teeth of the two combs with lampblack. On connecting the lampblack element with a telephone and battery, and exposing it to the influence of an intermittent ray, an intense musical sound is produced in the telephone.

65. By employing an induction coil the effects are intensified, and the sensitive elements can be employed as well for the reproduction of articulate speech as for musical sounds.

Fig. 68 shows the arrangement for a very interesting experiment based upon these two properties. When an intermittent current traverses the lampblack element A, or when an intermittent ray is thrown on the element through the mirror B, a powerful sound can be heard on applying the ear to the tube C. By the simultaneous action of an intermittent current and an intermittent ray, two distinct musical sounds are obtained, which produce a throbbing noise when their pitch is about the same.

66. Mr. Preece [1] and Mr. Mercadier have since Bell-Tainter's discovery greatly extended the field of radiophony; they have obtained by direct radiation sounds from all kinds of substances; but, as we have already stated above, for the demonstration of these phenomena no electrical contrivances are required, and they do not, therefore, enter into our *répertoire.*

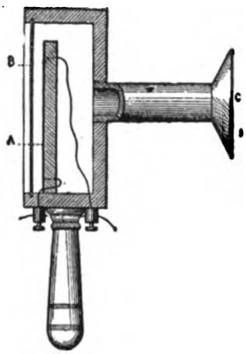


FIG. 68.

Graham Bell, in explanation of this fact, says [1]:—

"I think we are warranted in concluding that the nature of the rays that produce sonorous effects in different substances depends upon the nature of the substances that are exposed to the beam, and that the sounds are in every case due to those rays of the spectrum that are absorbed by the body."

Mr. Preece, [1] further explaining the phenomena, says:—

"When the rays of radiant energy fall on the black mass they convert it into a warmer substance, and in that condition the molecules of air strike it and rebound with increased velocity, thus producing greater pressure, which causes the air to expand. The air in expanding strikes the tympanum of the ear, which corresponds to these expansions, which are thus nothing more nor less than sonorous vibrations."

[1] W. H. Preece, "Journal of the Society of Telegraphic Engineers," May 12th, 1881.

67. An apparatus, however, has been constructed by Mercadier which is based on the electrical properties of selenium, and which may render valuable services for multiple telegraphic transmissions. Mercadier calls this apparatus—

Multiple Autoreversible Teleradiophone.

The apparatus consists of a number of selenium cells, which are constructed in the following manner :—

Two strips of very thin brass (about ·1 mm.) *a a′* and *b b′* (Fig. 69), one of which is represented in the figure by full and the other by dotted lines, are separated by two strips of parchment paper of about ·15 mm. thickness and of the same width, which serve as insulators, and may be considered as indicated in the figure by the blank spaces which are left between the lines. These four strips are coiled as close as possible into a spiral.

The block thus formed is placed between two brass plates *c* and *d*, one millimetre thick, which communicate with the two extremities *b′* and *a′* of the metallic strips, and the whole is squeezed as tightly as possible between two pieces of hard wood, or of brass, connected together by two long screws or two insulated rods M N with screw nuts. Two terminals A and B communicate with the plates *c* and *d*, and consequently with the extremities of the metallic strips, which form the one the even and the other the odd spirals.

The block thus formed is first roughly filed on its two faces, the surface is then filed as smoothly as possible, and finally polished with emery paper. The surfaces are then coated with selenium in a manner

[1] "La Lumière Electrique," iv. 1881, pp. 19, 295, 347.

similar to the one described in § 63, and the apparatus is allowed to cool down slowly. Excellent elements are thus obtained and can be made of very variable resistance—for instance, by selenizing only part of the surface, or by coating it first altogether and taking off the selenium by degrees. The resistance of these apparatus can thus be made to vary between 1,200 and 200,000 ohms, and they all produce very distinct sounds.

The arrangements for the transmission of speech with this apparatus are very simple. A series of selenium cells of variable resistance is placed at the sending station in circuit with a battery of a few elements and with the line which terminates at the receiving station by an equal number of receivers. Intermittent luminous radiations, interrupted like the Morse alphabet, are directed on the transmitters. The pitch of these radiations is fixed, but different for each transmitter. The corresponding telephonic receivers are arranged so as to respond to none but its corresponding tone. Every telephone will, therefore, produce a series of longer or shorter musical notes, which will be interpreted at the receiving station, like ordinary Morse signals. This conception of Mercadier has not yet received practical development.

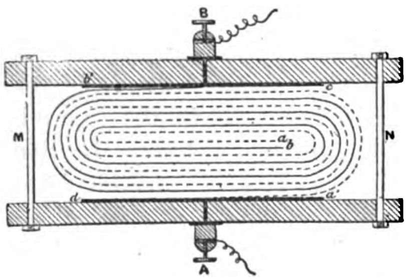


FIG. 69.

68. An ingenious apparatus has quite lately been introduced into practice, combining the properties of a call bell and a telephone, and which promises to

be of some value for domestic communication. It is called

The Button Telephone.[1]

The object of the instrument is to replace the press-button of an ordinary electric bell by a telephone-stud, which permits not only to ring up a person, but also to enter into conversation with him.

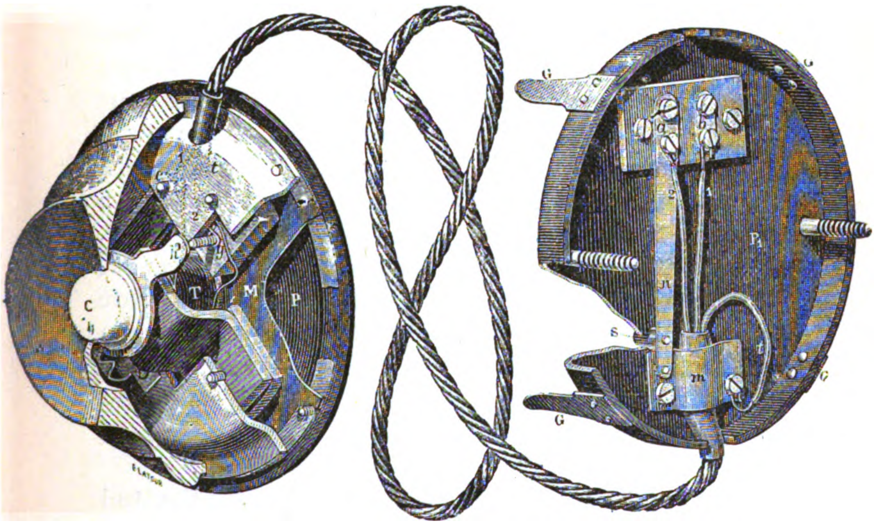


FIG. 70.

The apparatus consists of two parts, a socket fixed to the wall or to a small board, and a removable part which is taken in the hand when the telephone is to be used. The fixed and movable parts are connected by a flexible cord.

Fig. 70 gives the details, in actual size, of the different parts forming the apparatus, whilst Fig. 71 shows

[1] B. Marinovitch: "La Lumière Electrique," No. 1, 1886, p. 3.

a diagram of the connections. The letters on the diagram and on Fig. 70 being the same, it will be easy to follow the description.

On the right of Fig. 70 is represented the back of the socket; it consists of a metallic plate P, provided with a rim, on which are mounted four clamps G that grip the movable part when the apparatus is not in use. The plate P is fixed to the wall, or to a small board, by means of two screws shown in the figure. The two terminals *a* and *b* receive the wires which usually lead to an ordinary press-button. From these terminals start two wires, 1 and 2, which lead to the movable part of the apparatus. A third wire *t*, which forms with the two former a flexible cord, is in connection with a metallic contact *m*. Opposite *m* is an elastic plate *n*, connected to the terminal *a*, and carrying at its lower extremity a stud *s*, which traverses an opening in the plate P, and projects through it. By this arrangement, when the apparatus is not in use, the contact *m* and *n* is open; whilst it is closed through the elasticity of spring plate *n*, as soon as the front is withdrawn from the socket.

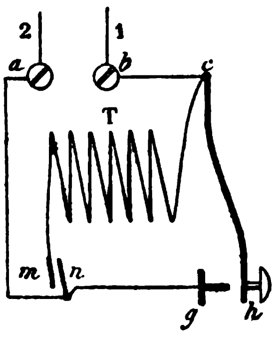


FIG. 71.

The movable part, the stud properly speaking, is to all intents and purposes, a telephonic receiver, of which M is the membrane, and T the coil, while *h* is an elastic plate placed opposite a contact *g*; the whole being enclosed in a wooden case having the form, and not much exceeding the dimensions, of an ordinary press-button. The plate *h* is in communication with the mass of the apparatus, whilst *g* is insulated from it.

By means of the flexible cord connection is made (1) between the mass of the apparatus, wire 1, and terminal *b* of the socket; (2) between wire 2 and terminal *a* of the socket; and (3) between one of the extremities of the coil and the contact *m* of the socket.

The other extremity of the coil is in communication with the mass of the apparatus. It will be seen that under these conditions diagram Fig. 71 represents the connections, the three strands of the flexible cord being represented by the portions of the circuit *b c*, *g a*, and T *m*.

The Phonograph.

69. Before passing on to the applications of the telephone, we must give a brief account of this apparatus, which created considerable sensation at the time of its invention by Edison, in 1877.

Fig. 72 represents the apparatus, which consists of a mouthpiece, across the inner orifice of which is stretched a metal diaphragm, and to the centre of this diaphragm is attached a point, also of metal. A brass cylinder is fixed upon a shaft, to which is also attached a crank and fly-wheel. The shaft is screw-threaded, and turns in a nut for a bearing, so that when it is caused to revolve, the cylinder has a horizontal travel in front of the mouthpiece. It will be clear that the point on the metal diaphragm must, therefore, trace a spiral over the surface of the cylinder. On the latter is cut a spiral groove of similar pitch to that on the shaft, and around the surface of the cylinder is attached a strip of tinfoil. When sounds are uttered before the mouthpiece the diaphragm is caused to vibrate, and the point thereon is caused to press with greater or less force on the tinfoil at the portion where the latter crosses the spiral groove. Hence, the foil, not being there backed by the solid metal of the cylinder, becomes indented, and these indentations are necessarily an exact record of the sonorous vibrations which produce them.

The reading mechanism is nothing but another diaphragm held in a tube on the opposite side of the

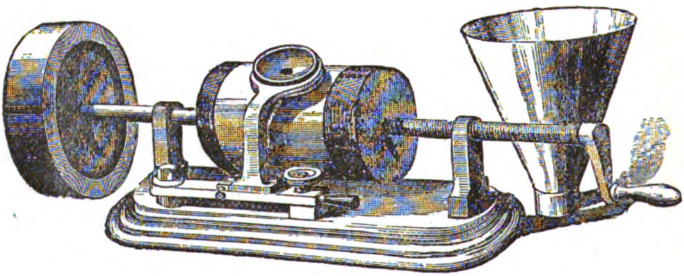


FIG. 72.

machine (to which is attached a funnel to reinforce the sounds) and a point of metal which is held against the tinfoil on the cylinder by a delicate spring. A lever, working on a pivot, brings the mouthpiece near to, or away from, the cylinder. Considerable modifications have been made in this apparatus recently (1888). Tainter has replaced the tinfoil by a wax cylinder, and uniform rotation, which is essential to correct reproduction of speech, has been obtained by Edison by an electro-motor, but the new instruments are not yet in the market.

Preece's Thermo-Telephone.

70. The original form of the instrument is shown in Fig. 73. A is a stout base of mahogany, on which a brass support C was attached so that it could slide, and be fixed at any distance from D, which is a disc of thin iron. A fine wire, *p p'*, is fixed to the centre of the disc, and stretched by means of the screw on C. Its loose

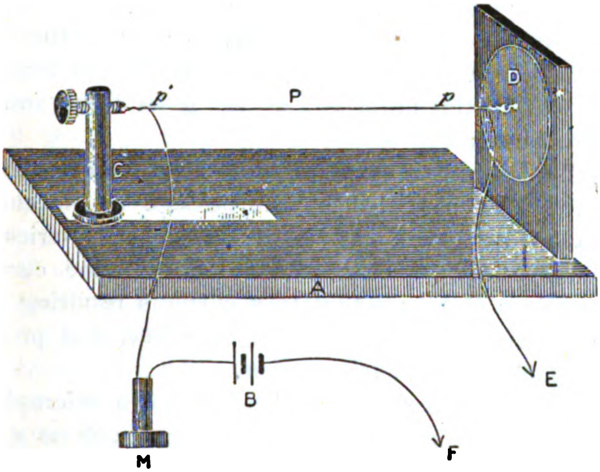


FIG. 73.

ends are connected to terminals on the wooden base, so as to be inserted in the circuit containing a microphone transmitter M and a battery B of six potassium bichromate cells.

A platinum wire of ·0076 cm. diameter, and 15 cm. long from *p* to *p'* was first used, and the sonorous effects

[1] "Proceedings of the Royal Society," April 28th, 1880.

were most marked when the microphone transmitter M was spoken into. The articulation, though muffled, was clear, and words could easily be heard.

The latest form of the instrument, which was exhibited in 1883 at Vienna,[1] has the form of a glass tube closed by a cork stopper and perforated by two wires which pass into the tube. A spiral of very thin platinum wire, about five centimetres long, connects the two wires. The undulatory currents in the platinum spiral produce molecular vibrations, and, consequently, expansions and contractions of the wire, whereby the air in the glass tube is thrown into vibration. An acoustic funnel is attached to the lower end of the glass tube, and the instrument can be used as a receiver.

All microphonic effects may be considered to be due to the heat produced by the passage of the current between two loose carbon contacts, which varies the resistance of the circuit, and therefore the currents themselves (§ 25); undulatory currents resulting from these variations are sent along the line, and produce analogous results in the receiver.

Now, if this explanation is correct, a microphonic transmitter must be reversible, just as much as a telephonic receiver; and such was shown by Professor Hughes to be the case.

A Red-hot Telephone Transmitter.[2]

71. Professor G. Forbes has recently made some experiments with a red-hot wire as a telephone trans-

[1] "Bericht über die Electrische Ausstellung," Wien, 1883, p. 289.

[2] Professor George Forbes, F.R.S., on "A Thermal Telephone Transmitter." Proc. Royal Society, February, 1887.

mitter. A fine platinum wire, from ·0025 to ·013 c.m. in diameter, and several centimetres long, was included in the circuit of a charged accumulator, and the primary wire of an induction coil. A receiving telephone was connected in circuit with the secondary wire of the induction coil. The battery power was such that the fine wire in the primary circuit was heated to a high temperature and rendered incandescent. When in this condition, on speaking to it the words could be heard in the receiving telephone. The explanation of the phenomenon is, that the sound waves passing the incandescent wire in quick succession altered its resistance by cooling, and thus varied the strength of current in the primary circuit. The fluctuations of current thus caused excited corresponding fluctuations in the secondary circuit, and these reproduced the voice in the receiver. Spiral wires in the form of watch springs, of steel and platinum iridium, were tried in place of the straight wire with some success. An indiarubber diaphragm was also interposed between the voice and the heated wire, and found to influence the wire like the direct voice. Mechanical vibration did not affect the apparatus.

CHAPTER IX.

ON THE COMPARATIVE EFFICIENCY OF SOME TRANSMITTERS.

72. TRANSMITTERS as well as receivers present the peculiarity that it is difficult to compare them with one another in the same exact manner that we compare, for instance, the electromotive forces of two batteries or the output of two dynamos. The estimates formed of different systems are matters of individual opinion, and it is rarely that several persons agree on the superiority of one system. It is, however, an admitted fact that a certain number of microphonic transmitters give nearly the same results, and that the slight differences, which always exist, cannot be detected by an ordinarily practised ear.

Professor Charles R. Cross, of Boston,[1] has made some practical tests in this direction; for this purpose he passed the currents produced in the secondary wire through a very sensitive Kohlrausch dynamometer whose resistance was 206 ohms. The vowels *a*, *o*, *u*, *i*, were sounded, as well as an organ pipe giving 512 vibrations per second. The transmitters tested were those of

[1] Rothen, "Journal Télégraphique," 1887, No. 2.

Edison, Blake, and Hunnings. The following table gives the result in milli-ampères:—

	a.	*o.*	*u.*	*i.*	Organ Pipe.
Edison ...	·088	·123	·144	·072	·072
Blake	·123	·144	·144	—	·132
Hunnings ...	·737	·787	·503	·213	·556

These figures clearly show that the Edison transmitter, with its lampblack lozenge, although its reproduction is very clear, gives relatively feeble currents, and that the Hunnings microphone is remarkable for its powerful effects. This confirms an observation which has been generally made, viz., that transmitters constructed with granular carbon of the Hunning's type (§ 51) are amongst the best known.

The induction coil of course plays an important part in the intensity and clearness of the reproduction; as a matter of fact it plays a much more important part than is generally believed, and there can be little doubt that a large number of transmitters might be sensibly improved by choosing more suitable induction coils. In these coils, as has been shown in § 12, the number of windings of each circuit is the essential, and the resistance is only the secondary consideration; the length and the thickness of the coils must therefore be taken into account.

Very many experiments have been made by the Post Office authorities in England in this direction; but the administration of the Swiss telephones has recently made very complete tests with 10 different coils constructed for the Blake microphone. They were tested by M. Abrezol, the chief of the Geneva district, over different distances varying from 5 to 107 kilometres. The construction of the coils was the following:—

No. of Coil.	Primary Wire: Number of Windings.	Primary Wire: Diameter of Wire in mm.	Primary Wire: Resistance in Ohms.	Secondary Wire: Number of Windings.	Secondary Wire: Diameter of Wire in mm.	Secondary Wire: Resistance in Ohms.
1	61	·5	·25	1,956	·15	100
2	62	·5	·25	3,191	·15	180
3	62	·5	·25	4,080	·15	250
4	116	·5	·50	3,952	·15	250
5	230	·5	1·00	3,865	·15	250
6	232	·5	1·20	4,420	·15	300
7	295	·5	1·50	4.278	·15	300
8	368	·5	2·00	4,735	·15	350
9	368	·75	1·17	4,735	·30	130·2
10	1,350	·5	10·00	3,950	·15	400

By means of a switch any one of these ten coils could, without loss of time, be placed in the microphone circuit, and the observer could in a few moments pass in review the whole of the coils, whilst retaining the impression produced from one test till the next. The results were obtained in connection with a good Blake microphone of American make, and an induction coil, whose primary wire had a resistance of 1·05 and secondary of 180 ohms

Expressing by the figure 1 the intensity and clearness of the standard coil, the ten coils gave the following results :—

Distances.		Induction Coil Number: 1	2	3	4	5	6	7	8	9	10
Geneva—Geneva ·5 Km. ...	Intensity	·3	·7	·9	1·5	1·3	1·5	1·3	1·3	1·7	·3
	Clearness	·9	·9	·9	1·3	1·0	·9	·9	1·0	1·0	·3
Geneva—Lausanne 61·6 Km.	Intensity	·9	1·0	1·0	1·7	1·3	1·6	1·5	1·5	1·6	·3
	Clearness	1·0	1·1	1·3	1·5	1·2	·9	·9	·9	·9	·5
Geneva—Vévey 79·1 Km. ...	Intensity	·3	·9	·9	1·3	1·1	1·7	1·1	1·1	1·7	·3
	Clearness	·7	1·0	1·0	1·5	1·3	1·3	1·1	1·0	1·4	·3
Geneva—Montenest 85·3 Km.	Intensity	·7	1·0	·9	1·3	1·3	1·7	1·5	1·5	1·6	·3
	Clearness	·8	1·3	1.3	1·5	1·5	1·6	1·4	1·4	1·6	·4
Geneva—Bex 107·4 Km. ...	Intensity	·2	·7	·6	1·2	1·0	1·5	1·6	1·6	1·7	·3
	Clearness	·9	1·0	1·0	1·5	1·3	1·5	1·3	1·2	1·3	·1

From this table which, taking into consideration the nature of the tests, shows a remarkable concordance, it will be seen at once that the coils Nos. 1 and 10 must be rejected. Coils 4, 6, 9 give the best results; coil No. 4 is the only one which, under all circumstances, gave clearer and more intense reproductions than the standard instrument. The clearness of reproduction gradually disappears with the increase of length in the actual circuit; the sound becomes more diffused and muffled, due to the interfering and retarding effects of self-induction. In this respect coil No. 9 is especially remarkable; at long distances it surpasses No. 4; but, since the same microphone must serve as well for the inner circle of a network as for long distances, a mean must be chosen, and nothing must be left to chance. On these grounds No. 4 ought to be selected. In Switzerland an induction coil has therefore been adopted, of the following construction:—primary circuit, 180 to 185 windings of wire of ·6 mm. diameter (No. 23 B.W.G.), and ·5 ohms resistance; secondary circuit 4,100—4,300 windings of wire of ·15 mm. diameter (No. 28 B.W.G.), and 250 ohms resistance.

73. It is highly probable that the coil which gives the best result in the Blake transmitter does not behave equally as well in other systems, and the experiments made with one single class of transmitters ought therefore to be multiplied.

A series of experiments in this direction have been made by Mr. Preece.

Five different forms of transmitters used in connection with various Continental Exchange systems were obtained and compared with that used in the Gower-Bell instrument (§35). They comprised the well-known forms of D'Arsonval (§ 38), Mix and Genest (§ 50), Berliner (§ 53), De Jongh (§ 49).

An artificial line, composed of a series of double-wound resistance coils and condensers, made up of sections, each of which had a resistance of 3 ohms, and a capacity of 1 microfarad, was employed for making the tests. The comparison was made by ascertaining the point at which articulation became indistinct with the different transmitters. They were connected to a switch by means of which any one of them could be included in the circuit and through the same coil, without practically interrupting the speaking, the remaining portion of the apparatus being undisturbed.

The results are shown in the following table. Column 3, the product of the capacity (K) and resistance (R), of the circuit represents the point at which articulation completely failed with each transmitter.

Transmitter under test.	Resistance Ohms.	Capacity. Micro-farad.	K×R	Remarks.
D'Arsonval	858	26	22,308	This result was only obtained after very careful adjustment.
Berliner	759	23	17,457	This transmitter was affected by moisture and K×R fell to 13,260 after two minutes' speaking.
Gower-Bell	693	21	14,553	
De Jongh	693	21	14,553	
Mix and Genest	402	14	6,468	

A comparison of the relative efficiency of the various induction coils with which these transmitters were furnished was made in like manner, the circuit being again arranged so that any one of the coils could be substituted for another by means of the switch, while the speaking continued.

The results are given below:—

Coil tested.	Dimensions.		Resistances.		Speaking limit. K×R
	Length (inside cheeks) Inches.	Outside diameter Inches.	Primary Ohms.	Secondary Ohms.	
Gower Bell	3¼″	1¾″	·5	250	14,553
D'Arsonval	2⅛″	⅞″	·7	173	13,200
Berliner .	2½″	1¼″	·0	188	13,200
De Jongh .	3¼″	1⅜″	·22	143	10,692
Mix and Genest .	1¼″	⅞″	1·0	157	13,200

It is thus seen that the results obtained by the British Post Office agree with those obtained by the Swiss administration.

74. The law which determines the distance to which speaking by telephone on land lines is possible, is just the same as that which Sir William Thomson has shown to be that which determines the number of currents that can be transmitted through a submarine cable in a second.

Every circuit has a time-constant dependent on the conditions of the circuit, invariable for the same uniform circuit but differing for different circuits. It represents the time that elapses from the instant contact is made at the sending end to the instant that the current begins to appear at the receiving end. It is given by the following equation :—

$$a = Bkrl^2,$$

B being a constant dependent principally on the units used ; k the inductive capacity per unit length (mile or kilometre); r the resistance per unit length, and l the length in miles or kilometres.

This time-constant therefore limits the number of vibrations per second that can be sent through any circuit.

The following table gives the resistance and capacity for the wires chiefly used in England :—

——	Capacity per mile microfarads.	Resistance per mile B. A. ohms.
No. 7½ iron wire	0·0168	12·0
No. 12½ copper wire	0·0124	5·7
Gutta percha-covered wire in iron pipes	0·2500	23·0
Gutta percha-covered wire in cables	0·2900	8·4

The distance to which one can speak is thus not a question of length; it depends on the resistance of the wire, on its inductive capacity, and also on its electro-magnetic inertia. The relative merits of iron and copper with their characteristics will be discussed in the next chapter. If we consider copper the only material that should be used for long circuits, because it is virtually free from electro-magnetic inertia, then we can say that the limiting distance through which it is possible to speak (S) varies with the product of the total resistance (R) and the total capacity (K), or the limiting distance

$$S = KR \times \text{constant.} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This is only another form of Thomson's law, for $K = lk$, and $R = lr$, and

$$\therefore S = krl^2 \times \text{constant.}$$

We can thus put equation (1) into this form,

$$A = krx^2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and if we give to A the following values (which have been obtained by experiment):—

Copper (overhead),................	15,000
Cables and underground..........	12,000
Iron (overhead).....................	10,000

we can find the limiting distance to which it is possible to speak with any wire; for

$$x^2 = A/kr.$$

Take copper, whose constant is 15,000 and a wire whose resistance is 1 ohm per mile, and capacity 0·0124 microfarad per mile, then—

$$x^2 = \frac{15000}{0·0124},$$

$$x = 1100 \text{ miles},$$

which is the extreme distance at which speech can be reproduced upon such a wire. Of course the constants which give us the distances at which speech is easy and practical are less than these. They are as follows:—

Copper (overhead)..................	10,000
Cables and underground	8,000
Iron (overhead).......................	5,000

When the product K × R gives a number less than those, speech will be easy.

75. There is a very interesting consequence of Thomson's law, and that is, whether the line be a single wire completed by the earth, or a double wire making a metallic circuit, the rate of speed between the two ends is exactly the same, and therefore the distance we can speak through is just the same whether we use a single or double wire circuit. This is owing to the fact that though in the latter case we double the resistance, we

halve the effective capacity, and therefore the product remains the same.

The difference between copper and iron is due to the presence of self-induction, or to the electro-magnetic inertia of the latter, and the difference between copper overground and copper underground is due to the facility that the leakage of insulators at so many points, offers to the rapid discharge to earth of the static charge, while in gutta percha-covered wire, its only exit is at the ends.

There is no difficulty in working telephones through underground wires, when they are properly designed, even though they attain 50 miles in length.

The limit of working of different insulated wires is easily obtained by equation (2), and the following table gives that information for different gutta percha-covered wires.

Size of Wire.*	*k.*	*r.*	Limit of speech
$\frac{20}{11}$	0·270 mf.	45·00 ohms.	32 miles.
$\frac{18}{7\frac{1}{2}}$	0·250 ,,	23·00 ,,	46 ,,
$\frac{16}{4}$	0·240 ,,	13·00 ,,	62 ,,
$\frac{14}{2}$	0·290 ,,	8·4 ,,	70 ,,

* The top number indicates the gauge of wire, and the lower number that of the gutta percha. A table of the British wire gauge is given at the end.

CHAPTER X.

TELEPHONE WIRE.

A.—Air Lines.

76. Two sorts of wire are chiefly used for the construction of telephone lines: *iron* and *copper*.

In a network of wires, where many hundreds run alongside and cross each other in all directions, it is above all things necessary to select the *strongest* possible wire, in order to prevent as much as possible any breaking, which would be a source of the greatest inconvenience. Not only would the breaking of one wire most seriously interfere with the working by entanglement with other wires and so produce contacts, but the overhead wires falling down would impede the traffic.

In selecting the localities for the establishment of the wire supports, local conditions and, in many cases, personal prejudices have to be taken into consideration, and long spans are thereby rendered necessary, which tax the strength of the wires and their supports to the utmost.

On these grounds steel wire naturally commends itself for telephone lines; and both for the sake of economy and also of security, a wire of the smallest possible diameter, so as to be of the least possible weight. While in London a stranded wire of 3 strands of No. 18 wire is employed, a galvanised steel wire of about 2mm. diameter (No. 12 B.W.G.) which can bear a stress of about 440 kilogrammes (900lbs.) is much used. But the electrical resistance of this wire is high, amounting on an average to 54 ohms per kilometre (nearly 100 ohms per mile). This drawback, however, scarcely makes itself felt in the case of urban lines, where distances are limited.

The coating of zinc which the steel wire receives by the process of galvanising is most important, because the lines frequently pass directly over chimney stacks and fire-places, which give off deleterious gases that would soon destroy the steel. Even the zinc coating cannot entirely withstand this destructive influence. Under unfavourable conditions a steel wire may be entirely destroyed in two or three years. In especially exposed localities wire is employed which is protected by a serving of hemp or tape coated with an insulating substance, and this wire is stated to remain serviceable for many years.

Copper wire has, however, of late years, superseded steel wire to a great extent. Pure copper wire as now made is actually stronger than iron wire of equal diameter, and approaches in tensile strength the best steel wire. Additional strength has also been given to copper by the addition of certain substances, such as chromium, phosphorus, or silicium, and also by special treatment in the process of wire-drawing (hard-drawn wire). The wire does not by these special processes lose much of its conductivity, whilst it gains enormously in mechanical strength.

For telephone lines a wire of ·8 mm. diameter (No. 21) is much used, which is six times lighter than the steel wire of 2 mm., and therefore permits of a much lighter description of support. Another advantage is that this fine wire is much less visible, and therefore much less of an eyesore than the heavier steel wire.

77. But the electrical properties of copper wire are even more valuable for telephony than its mechanical qualities. We refer, of course, to its higher conductivity, as well as to the absence of electro-magnetic inertia (§ 74). Mr. Preece [1] has found, as the result of a large number of experiments made with an iron and a copper wire between London and Newcastle, that the increase of speed in electrical transmission through a copper wire over that in an iron wire is from 11·19 to 21·00 per cent., or a mean increase of 16·1 per cent.

Prof. Hughes[2] has shown that that which he calls "inductive capacity" of copper, taking that of soft Swedish iron at 100, is only 20. This inductive capacity, however, is, according to Professor Hughes, not only dependent upon the physical condition of the conductor but also upon its form, and is something more than mere electro-magnetic inertia; a stranded conductor, for instance, made up of thin iron wire, is stated by Professor Hughes to have a smaller inductive capacity than a plain copper wire of the same cross section.

Another and most important advantage of copper wire is its low electrostatic capacity. If we take a copper wire and an iron wire of the same resistance, the former having a diameter of 2 mm., the latter would show a diameter of ·8 mm. The copper wire would be six times lighter than the iron one, and its

[1] Paper read before the British Association at Aberdeen, 1885.

[2] Inaugural address delivered before the Society of Telegraph Engineers, 28th January, 1886.

surface would be two and a half times smaller. The wire would, therefore, be more easily insulated and its *electrostatic capacity* would be smaller. We must look upon an air wire as a condenser whose one coating is the wire, the other coating being the earth, and the intervening air the insulating medium. The electrostatic capacity of an air-line (K) is determined by the formula :—

$$K = \frac{l}{2 \log (4h/d)}$$

where l is the length, h is the elevation of the wire above the ground, and d its diameter.

78. Experiments made on the telegraph lines in the North of England, showed that the mean height of the copper wire above the ground is 6·90 metres, and that of the iron wire (fastened to a lower point of the same posts) 6·60 metres. The diameters are 2 mm. and 4·27 mm. respectively. K for the copper wire, came out by calculation =4·1398791, and for the iron wire 3·7906078,

$$\text{Hence } \frac{3{\cdot}7906078}{4{\cdot}1398791} = {\cdot}916$$

This gives the capacity of the copper wire 8·4 per cent. less than that of the iron wire. This result agrees very fairly with the mean value of the differences of capacity as determined by the direct measurements taken, which gave 9·1 per cent. The mean capacity of a single iron wire of 4·27 mm. diameter, stretched about 6 metres above the ground, was found to be ·0131 microfarad per mile; whilst an iron wire of the same diameter and stretched at the same height, but surrounded by other wires, would have a mean capacity of ·0169 microfarad per mile. The capacity of a copper wire of 2 mm. diameter would under similar conditions be about ·0120 and ·0142 microfarad per mile respectively.

79. There is yet another advantage in the use of copper wire for telephone lines, and that is, that the wires are much *less noisy* than those constructed with iron wire. Besides those *noises*, which are the result, either of mechanical vibration or of induction of one telephone or telegraph wire upon another, other noises occur which are the result of terrestrial causes. Every wire lies in the magnetic field of the earth, and when the wire in this field is thrown into a strong vibratory motion by strong winds, currents are induced in it. Such currents are especially observed in lines which have the direction from north to south, and thus by their vibrations cut at a right angle the lines of force of the earth. They manifest themselves much more strongly in iron wires than in copper ones, because the former behave themselves like linear magnets and concentrate the lines of force.[1]

80. There are of course other noises arising from currents of a different kind, which occur in copper as well as in iron wires. When the two ends of the wire are led to earth, the two earthplates, as a rule, will not possess the same potential, especially where the two points have a different position with regard to the elevation and the geological condition of the ground. A continuous current is thus engendered in the wire, which in itself has no effect upon the telephone; but if it become intermittent, for instance, through the

[1] Weitlisbach Die Tecknik des Ferrsprechens, Wien, 1886, p. 109.

variable resistance of a bad joint which is moved by the wind, or through variable insulation caused by rain, or through electrolytic action on the earth-plates, disturbances will ensue. These intermittent disturbances, which on a long line may repeat themselves at very short intervals, are very troublesome, especially in wet weather. It must be recorded that one end of the line may be perfectly quiet, while the other end is so noisy that correspondence becomes impossible. This is frequently the case when atmospheric electricity is about. These facts clearly show that it must not be assumed that in long lines an electric disturbance travels over the whole line. Such a disturbance may be confined to one portion of the line only, and not affect the remainder at all.

81. It is necessary that we should here draw attention to the fact that copper wire requires great care in every way. The wire adopted by the British Post Office is subject to very strict inspection. It is carefully gauged and tested for ductility and tensile strength. It is wrapped in six turns round its own diameter, unwrapped and again wrapped in the same way; and it must do this without breaking. A piece is then gripped by two vices at a distance from each other of 7.5 cm., one being fixed, and the other slowly revolved until the wire breaks. The number of twists the wire withstands is shown by an ink mark put on the top of the 7.5 cm. piece before the test commences, and which forms, as the wire is twisted, a spiral on the wire, whose number of convolutions is easily counted.

The test for tensile strength is made by direct application of a stress slowly augmented until the wire breaks.

It is very desirable to draw a distinction between *stress* and *strain*. The strain of a body is the proportion of itself by which it lengthens. It is therefore a distortion. The stress is the load per square centimetre or per square inch which produces this strain. It is therefore a force. Stress is cause, strain is effect. The tensile strength of a wire is the stress it will bear before it breaks. It is frequently called the *breaking weight*. The elastic strength is the stress which produces a permanent set, and it indicates the *limit of elasticity*.

In course of erection great care has to be exercised with copper wire. Coils must not be carelessly thrown about, as they may be without harm in the case of iron wire. Flaws, indentations, scratches, kinks, and similar injuries act very much in the same way as diamond scratches on glass:—they make the wire brittle. Special drums therefore, fitted with brakes, have been designed and made so that the coils of wire may be unwound under tension, and so prevent the possibility of kinking, or putting unnecessary turns in the wire.

The joints are the ordinary Britannia joints (Fig. 74) whipped with No. 20 tinned copper wire, chloride of zinc

FIG. 74.

or Baker's fluid[1] being used as a flux in soldering. It is very necessary to avoid the continued application of heat, for heat softens and weakens the wire; quick soldering is therefore essential.

82. Leaving now the consideration of the material of

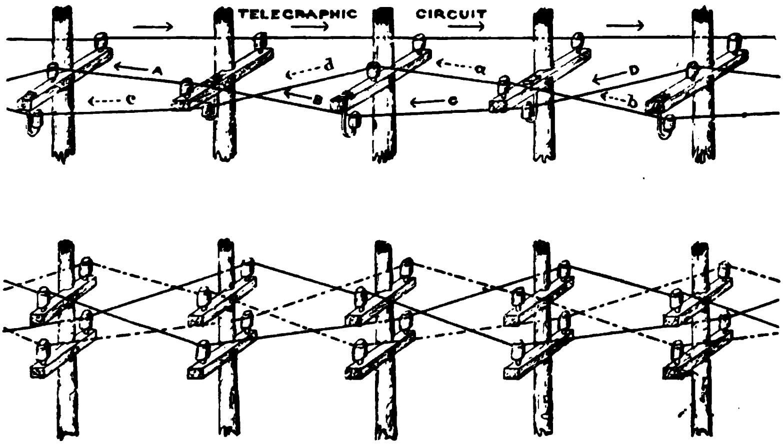
[1] Zinc, hydrochloric acid, and ammonia.

the wire, we pass on to another most important point—the *insulation* of the line. In the early days of telephony the distances of telephonic transmission were of such a limited character that a less perfect insulation was no serious hindrance; but this is entirely altered now that we have telephonic communication extending over great distances. Experience has shown that insulation has a marked effect upon clear transmission.

In the first instance, loss of current and consequent weakening of the transmitted sounds is one of the results of imperfect insulation. Every point of attachment of the wires must be looked upon as a more or less efficient earth shunt. If the insulation is good, the shunted current is small; if it is bad, the latter increases, and several thousands of these points of attachment, which must naturally occur on long lines, will have a most deteriorating effect upon the intensity of the transmitted currents.

83. Another drawback is that when a number of parallel wires are attached to the same support, the shunted current passes not only to earth, but also (and often perhaps for the greater part) into the neighbouring wires, increasing with the number of points of attachment which the wires have on the same pole. Thus it can easily happen that the contacts become strong enough to allow of the conversation carried on on one wire to be heard in the telephones of the neighbouring lines. This undesirable effect may be caused not only by contact, but also by *induction*. With this latter phenomenon we have already dealt in Chapter II. But we may here describe a plan which has been devised in order to neutralise the effect of this induction upon telephonic circuits. At a very early stage of telephony

it was found that a two-wire telephone circuit was much freer from disturbances than a single wire circuit, and Professor Hughes further pointed out that if the wires were twisted around each other, the effect of the disturbances was still further eliminated. This was put into practice by the late Mr. Charles Moseley between Manchester and Oldham. It is now carried out in the manner



Figs. 75, 76.

shown in Figs. 75 and 76. It will be observed that the wires make a complete revolution in four spans of the line, and so this keeps the two wires at the same average distance from all external disturbing influences; such, for instance, as a working telegraph circuit, or another telephone wire. Thus, in Fig. 75 the disturbing influence of the telegraph wire upon the spans A, B, C, and D, of one wire of the telephone circuit is exactly counteracted by the same disturbing influence upon the corresponding spans *a*, *b*, *c* and *d* of the return wire. Fig. 76 shows the arrangement made where two telephone circuits are run upon the same poles.

For the above reasons the most perfect insulation practicable is not only desirable, but absolutely necessary.

For the purposes of insulation, porcelain insulators of the same form as those used for telegraph lines are generally employed.

84. The distance between the insulators must be decided by the consideration that not even a strong wind shall cause an entanglement of the wires. Experience has shown that for medium spans a distance of 40 centimetres is the minimum that should be allowed, provided no joints occur in the section. For shorter spans 30 centimetres, and for spans of more than 200 metres, 50 centimetres ought to be the minimum adopted. The quality of the wire also must be taken into account: for copper wire of ·8 mm., and short spans 20 centimetres are sufficient. In the British Post Office the distance between the wires is 18 inches (45 centimetres).

85. Another consideration which is of the highest importance for telephonic networks of wire is the length of *sag*, or *dip*, of the wires between two supports.

So much depends on the care and accuracy with which copper wire is erected that an entirely new mode of wiring or putting up the wire has been introduced. Hitherto it has been customary to regulate the sag of iron wires by reference to a dip of 24 in. in 100 yards, and to vary this for different spans and temperatures by reference to tables; but foremen were governed very much by rule of thumb, and regulated simply by eye.

This would never do for copper; so special dynamometers, or draw vices (Fig. 77), have been designed and fitted with Salter's springs, properly graduated, and the wire is always regulated to its proper tension.

The variation in the length of wire in a span, owing to changes of temperature, necessarily has the effect of varying the stress on the wire; this, therefore, has to be provided for in erecting wires, and, in connection with the introduction of the dynamometer just referred to, the British Post Office has issued a table which is given below and which shows the corresponding sags and stresses of iron and copper wires under varying temperatures.

This table is based on a factor of safety of 4 at the minimum temperature 5° C. for all wires; that is to say, that wires erected according to the table will never have to bear a stress of more than one quarter of their nominal breaking stress as long as the temperature does not fall below 5° C.

TABLE SHOWING SAGS AND STRESSES WITH VARYING SPANS AND TEMPERATURES FOR IRON AND COPPER WIRES.

400 LBS. IRON WIRE (No. 7½).

Span.	Low Winter Temp.		Ordinary Winter Temp.		Average Summer Temp.		High Summer Temp.	
	Sag.	Stress.	Sag.	Stress.	Sag.	Stress.	Sag.	Stress.
Yds.	ft. in.	lbs.	ft. in.	lbs.	ft. in.	lbs.	ft. in.	lbs.
100	3 1¾	270	3 9	227	4 3¼	200	4 8⅞	180
90	2 6⅝	270	3 1¾	219	3 2¾	190	4 0⅞	169
80	2 0¼	270	2 7⅛	210	3 0¾	178	3 5⅞	157
70	1 6½	270	2 1¼	198	2 6½	164	2 10⅞	143
60	1 1⅝	270	1 8	184	2 0¾	148	2 4¾	128
50	0 9½	270	1 3½	165	1 7¾	130	1 11¼	110

150 LBS. HARD DRAWN COPPER WIRE (No. 12½).

Span.	Low Winter Temp.		Ordinary Winter Temp.		Average Summer Temp.		High Summer Temp.	
Yds.	Sag. ft. in.	Stress. lbs.	Sag. ft. in.	Stress. lbs.	Sag. ft. in.	Stress. lbs.	Sag. ft. in.	Stress. lbs.
100	2 8	120	3 7	89	4 5⅞	74	4 11½	64
90	2 2	120	3 1	84	3 9½	69	4 4⅛	60
80	1 8⅜	120	2 6⅞	80	3 2½	64	3 8⅞	54½
70	1 3⅝	120	2 1¾	73	2 8⅝	57½	3 2½	49
60	0 11⅝	120	1 9	66	2 3⅛	51	2 8¼	43
50	0 8	120	1 4⅝	58	1 10	44	2 2⅜	36½

100 LBS. HARD DRAWN COPPER WIRE (No. 14).

Span.	Low Winter Temp.		Ordinary Winter Temp.		Average Summer Temp.		High Summer Temp.	
100	2 8	80	3 7	59	4 3⅞	49	4 11½	43
90	2 2	80	3 1	56	3 9½	46	4 4⅛	40
80	1 8⅜	80	2 6⅞	53	3 2½	42½	3 8⅞	36
70	1 3⅝	80	2 1¾	49	2 8⅝	38	3 2½	33
60	0 11⅝	80	1 9	44	2 3⅛	34	2 8¼	29
50	0 8	80	1 4⅝	39	1 10	29	2 2⅜	24

The stress for 200 lbs. (No. 10½) iron wire is half that for 400 lbs. iron wire.

The stress for 200 lbs. (No. 11½) copper wire is double that for 100 lbs. copper wire.

The minimum temperature is taken at −5° C. Ordinary winter temperature may be taken at 5° C., average summer temperature at 12° C, and the temperature of a hot day at 26° C. These figures serve the same practical purpose as the use of thermometers, which, if placed in the sun, would not, as a rule, record the actual temperature of a wire in course of erection.

The stress, as measured by the dynamometer, should in all cases correspond with that shown in the table for a given conductor and average span under the temperature prevailing during the erection of the wire. This stress, as already stated, will vary for different spans at the same temperature, but for any given line the figures opposite the average span and temperature are those employed in practice.

Sags and stresses for copper and iron wires do not vary in the same ratios under changes of temperature, owing to copper having a higher co-efficient of expansion than iron. With spans of less than eighty yards the difference is not so great as to render it unsafe to run iron and copper wires together; but as spans increase beyond this length some danger of contacts may arise, and a slight departure from the tabular results may then be permitted to obviate this difficulty. For example, in special instances the copper may be run with a greater dip, or the iron with a lesser one. It is, however, better not to run copper and iron together on spans exceeding eighty yards.

The dynamometer referred to is shown in Fig. 77. It consists essentially of a strong steel spring, called Salters' spring, enclosed in a brass tube. A special grip is fastened to one end of the spring, while the other end is fixed in the tube. According as the grip is pulled out more or less, the traction exercised on the steel spring is stronger or weaker, and can be read off on a scale engraved on the piece which joins the hook and the spring. The wire is first placed in the grip, and the tube being pulled back by a ring until the scale indicates the required tension, the wire is attached to the insulator in the manner described on page 145, Fig. 79.

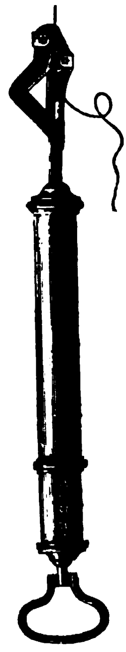


FIG. 77.

This method is now exclusively used by the British Post Office in the erection of copper wire, and also with iron wire, where lines of copper wire are likely to be run on the same poles.

86. Mr. Rothen,[1] the Assistant Director of Swiss Telegraphs, has also calculated the dip for different spans and temperatures, basing his calculations on the coefficient of expansion of steel wire of 2 mm. diameter, and on the rule that the stress of the wire must never exceed 60 kilograms. The results of his calculations are given in the following table:—

Span in metres.	Dip in centimetres at different temperatures in degrees Centigrade.										
	−25°	−20°	−15°	−10°	−5°	0°	+5°	+10°	+15°	+20°	+25°
50	13	28	36	43	49	53	57	62	67	71	76
60	20	34	44	50	58	63	70	77	80	85	88
70	25	41	52	61	70	76	83	88	93	100	104
80	33	47	60	70	80	90	97	102	108	113	118
90	41	58	70	80	90	100	108	115	120	128	134
100	54	68	83	95	107	114	123	132	141	150	156
120	75	90	106	120	131	140	154	164	174	182	188
140	100	118	136	150	162	176	187	197	207	217	226
160	128	146	163	180	196	207	220	230	240	250	264
180	164	182	200	214	227	240	257	268	278	290	303
200	211	228	248	263	278	290	306	317	330	340	347
250	321	340	360	375	390	410	423	438	448	458	466
300	462	482	502	520	540	560	575	590	605	620	636
350	638	660	680	700	720	738	756	770	787	800	814
400	830	850	875	897	920	936	950	970	980	1008	1026
500	1280	1300	1325	1350	1368	1375	1400	1420	1435	1455	1470
600	1825	1850	1870	1890	1920	1940	1965	1990	2015	2040	2065
700	2515	2550	2275	2605	2640	2670	2695	2720	2750	2773	2800

In connection with this table we may draw attention to two remarkable peculiarities, which, of course, equally apply to all such tables.

The first is the rapidity with which the dip increases with the increase of the span, and the second is the difference of the proportional lengthening of the dip by the rise of temperature, both for large or for small spans.

Thus, for instance, a wire of 50 metres span requires at + 10° a minimum dip of 62 centimetres; whilst

[1] Journal Télégraphique, vol, vii., p. 101.

another wire of 700 metres span requires at the same temperature a dip of 2,720 centimetres. On the other hand, in the case of short spans, the dip increases rapidly with the rise of temperature, whilst for long spans this increase is comparatively small. The dip of a wire of 50 metres span increases by about 600 per cent., from $-25°$ to $+25°$; whilst that of a wire of 700 metres span, under the same conditions, rises only by 12 per cent. From this it results that we have nothing to fear from low temperatures for long spans, but that they can become fatal for short ones, if, by inadvertence, the dip has been made too small.

Mr. Rothen has also compiled the following table, which indicates the stress, in kilograms, which the wire is subjected to under the afore-named conditions when it is required to find the proper suspension of the wire by means of a dynamometer:—

Span in metres.	Stress in kilograms for different temperatures in degrees Centigrade.										
	−25°	−20°	−15°	−10°	−5°	0°	+5°	+10°	+15°	+20°	+25°
50	60·0	27·5	22·3	18·8	16·4	14·7	13·5	12·5	11·6	11·0	10·5
60	60 0	33·0	26·0	22·0	19·2	17·2	15·9	14·7	13·8	13·0	12·6
70	60·0	37·0	29·4	25·0	22·2	20·0	18·5	17·0	16·2	15·3	14·6
80	60·0	41·0	32·6	27·6	24·6	22·3	20·6	19·0	18·2	17·2	16·3
90	60·0	43·7	31·6	30·3	27·0	24·5	22·8	21·4	20·1	19·0	18·0
100	60·0	45·4	37·8	32·6	29·5	27·0	25·1	23·5	22·0	20·7	19·7
120	60·0	48·2	41·3	36·5	33·1	30·8	28·8	27·3	25·7	24·6	23·7
140	60·0	50·7	44·8	40·4	37·1	34·5	32·7	31·0	29·5	28·2	27·2
160	60·0	53·0	48·2	44·0	40·7	38·0	36·0	34·2	32·6	31·4	30·4
180	60·0	54·4	50·0	46·3	43·2	40·6	38·5	36·7	35·1	33·9	33·0
200	60·0	55·4	51·7	48·5	45·7	43·5	41·3	39·5	38·0	36·6	35·6
250	60·0	56·2	53·3	50·8	48·6	46·0	44·7	43·2	41·9	40·9	40·0
300	60·0	56·9	54·6	52·6	50·8	49·2	47·7	46·5	45·4	44·4	43·4
350	60·0	57·3	55·4	53·7	52·5	51·2	50·0	48·9	48·0	47·0	46·2
400	60·0	57·7	56·2	54·9	53·7	52·7	51·7	50·7	49·9	49·3	48·7
500	60·0	58·1	57·0	56·0	55·2	54·4	53·6	53·0	52·4	52·0	51·7
600	60·0	58·4	57·5	56·7	56·2	55·6	55·2	54·8	54·5	54·3	54·2
700	60·0	58·6	57·7	57·2	56·6	56·4	56·0	55·6	55·4	55·2	55·0

This table shows that the stress on wires with a short span increases very rapidly with decrease of temperature, whilst wires having a long span very nearly preserve their primitive tension. From this it results that a wire of 50 metres span would infallibly break at $-25°$ if it were subjected at $+25°$ to a stress of, say, 15 kilograms, instead of the admissible maximum of 10·5 kilograms.

87. The stress of a wire rapidly increases by the deposition of snow and ice. These deposits often form on a single wire cylinders of several centimetres diameter. The specific gravity of snow is ·12, and that of ice ·92; for a mixture of both, of which these deposits are generally formed, we may assume a specific gravity of ·3. A deposit of 3·58 mm. thickness will, therefore, be sufficient to double the weight, and consequently also the stress of a steel wire of 2 mm., whose specific gravity is 7·2. It has been observed that larger masses of ice are deposited on a copper than on an iron or steel wire, which observation, as might be expected, agrees with the difference of specific heat of the two metals.

The length of the dip is sometimes determined by means of a graduated ruler, which is held up in the centre of the span on a level with the two points of attachment. The wire is then slackened so far until it shows the desired dip on the graduated ruler. It is often difficult, however, to do the necessary sighting, for instance, when the span leads over a valley or a river. In such cases the requisite dip is measured vertically downward on the two supports from the points of attachment, and the wire is stretched until its vertex touches the sighting line between the two points. The plan of measuring the stress by means of a dynamometer is, however, unquestionably superior, both as to convenience and practical results.

The following table gives the wires most frequently used for telephony and their most important properties.

——	Diameter in Millimetres.	Gauge.	Weight per Kilometre in Kilograms.	Resistance per Kilometre in Ohms.	Conductivity Pure Copper = 100.	Tensile strength in Kilograms.
Iron Wire	5	6	156	65	14	780
....	4	8	100	10	14	500
....	3	11	56	18	14	300
Steel „	2	14	25	54	10	440
Phospor Bronze................	·8	21	4·5	108	30	38
„ „	1·2	18	10·1	42	30	80
Copper	2	14	28	5·6	97	150

88. When the system of telephonic wires in a district becomes very extensive it is necessary to provide specially constructed frames to support the wires, as ordinary poles cannot be made to meet the requirements. One of these special frames, recently erected by the United Telephone Company in London, is shown in Frontispiece, in which (as it is shown in course of erection only) the poles which it replaced may also be seen.

89. The connection of the main line and the service leads, is made thus:—

From the nearest trunk line, or that line from which the subscriber's house can be most conveniently reached, the branch line, or (if it is an intermediate station that is to be established) the loop-line, is brought to the house where the telephone is to be fitted up.

Should there be any difficulty in the use of the ordinary open conducting wire, the wire connecting the line to the telephone can be inserted in a leaden tube and thus secured against injury. Beneath the insulator which terminates the branch-wire, the wall is pierced

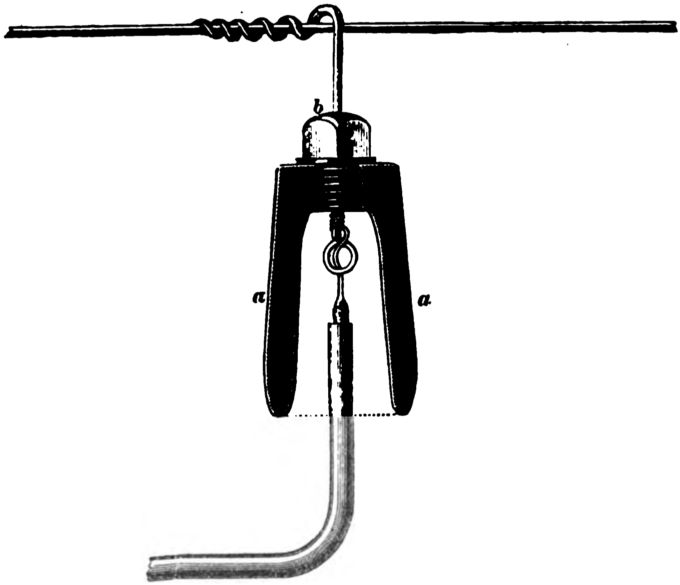


Fig. 78.

and the service-wire or lead cable, introduced in the opening, and a few centimetres of the copper core are laid bare. To prevent the current from passing in wet weather from the air-line, over the damp insulated coating of the cable core, to the lead covering and thus to the damp masonry, a special insulator (Fig. 78) is often placed between the air-line and the service wire.

We illustrate the German pattern. It consists of a casing *a* and a head-piece *b* screwed into it, both made of hardened indiarubber. A wire passes through *b* into the case *a*, and there terminates in a small loop; care being taken to insert the wire in *b* sufficiently tightly to prevent the least trace of moisture from penetrating into the interior of *a*.

The end of the wire passing through *b* is wound several times round the air-line and soldered to it. The

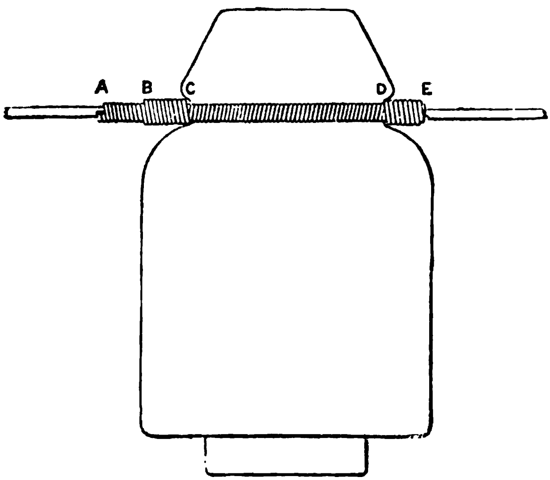


FIG. 79.

first convolutions are, as will be seen from the figure, somewhat loose and not soldered, to prevent the wire from breaking. The case is then screwed off, the core of the leaden cable is introduced, the metallic bared extremity is passed through the loop of the wire, wound round it several times and soldered; the casing is then finally screwed on the head-piece. The connection must be made in such a way that the covering of the leaden cable penetrates a short distance into the casing and hangs down perpendicularly in the centre of the insulator, so that the rain cannot penetrate between the leaden covering and the indiarubber coated wire.

The method of binding copper wire to the insulator is shown by Fig. 79. Two wires are whipped round the line wire from B to E, thence back to D, then from the *upper* side of the line wire they are taken around the neck of the insulator to the *under* side of the line wire at C, back over the first layer to B, and then taken on as a single layer to A.

90. A good earth connection, where single wires are used, is a matter of the utmost importance; it not only contributes to the clear reproduction of speech, but also weakens the disturbing noises of the telephone, and careful execution of this detail is, therefore, a most important factor in a telephonic installation. A common earth connection is made for the battery as well as for the telephone circuit.

In towns having a universal domestic water-supply, water-pipes are most conveniently used for this purpose. The copper-wire used for earth-connection is conducted to the nearest water-pipe—if possible, to an ascending main-pipe—and carefully soldered to it. An excellent and most efficient earth-connection is obtained in this way, the whole net-work of pipes acting as a conductor.

The use of gas-pipes for earth-connection are objectionable, because the pipes inside the houses are generally joined together by means of red or white lead, so that a considerable resistance would be introduced. In certain circumstances this might lead to very great inconvenience; if, for instance, the earth-connection of two telephones used in one house is made by means of the gas-pipes, it may easily happen that the currents employed for the use of one telephone, instead of going direct to earth, would pass through the earth-connection into the other telephone, and, therefore, the words spoken before the one are heard in the second telephone.

Where there are no water-pipes available, a good separate earth connection must be made. If there is a pump in use near at hand that will furnish a very satisfactory earth, if the wire is carefully soldered to it; but in all such connections great care must be taken to ensure that the solder thoroughly adheres to the metal. Again, a plate of galvanised iron, or, better, copper, about two or three feet square, buried in ground that is always damp, is a plan of obtaining good "earth" often adopted.

On short circuits it is very important to secure the same sort of metal for earth connection at both ends, otherwise the dissimilar metals of the earth-plates connected by a conductor furnish the conditions for a current, which may become a source of serious disturbance in the circuit.

B. Cables.

91. The employment of cables for telephonic communication has lately become most urgent owing to the ever-increasing number of aerial lines in large towns. This necessity chiefly exists for the lines starting from a central office up to that point where the wires begin to branch off in different directions. The number of starting wires becomes so large that one supporting frame

can no longer accommodate them ; two, three, or even more, large frames have to be erected, only to be filled up in their turn, and to leave the need of fresh erection.

Two sorts of cables can be, and have already been used for this purpose :

1. Aerial Cables.

2. Underground Cables.

The main difficulty which opposes itself to the employment of cables is the induction of one strand upon the other, which, as already mentioned (§ 83), would enable a conversation carried on in one strand to be heard upon another.

In order to reduce the inductive effects to a point which will no longer affect the working, each telephonic line must either be provided with a separate return wire, and the respective strands forming the outward and return line must be arranged in such a manner that an imaginary plane passing through them does not run parallel to another plane passing through a second outward and return wire ; or special means must be resorted to for weakening the induction.

The former method, which has been systematically employed by the British Post Office from the very first, is by far the more efficient plan, besides having the further advantage (already referred to in § 80) that it eliminates the effect of earth currents.

The employment of two wires for one speaking line, however, somewhat increases the expense of the installation, and other methods have, therefore, been devised to weaken the inductive effect in long lines.[1] In the first cables which were constructed by the British Post

[1] W. H. Preece, "On some Physical Points connected with the Telephone," Phil. Mag., April, 1878.

Office, in 1878, with this object, every individual insulated strand was surrounded by a coating of thin lead or tin-foil, which had been firmly pressed around it. This shielded arrangement of Mr. Preece's, however, was only a partial solution of the difficulty, and, in order to make it thoroughly effective, it has been found necessary that all the protecting coatings should be connected not only amongst themselves, but also to earth, and be very heavy. Very many modifications of these shielded cables have since been introduced in different countries.

The efficiency of the lead covering is not due to the fact that it acts as a shield between one wire and another, but that it forms a return circuit for the currents surrounding the prime wire. Hence any external disturbances due to induction affect both parts of the current equally, but in opposite directions and are thus rendered nugatory.

1.—Aerial Cables.

The principal requirements for an aerial cable are:—

(*a.*) The smallest possible relative weight per metre.

(*b.*) The highest possible relative tensile strength so as to withstand the stresses due to wind pressure.

(*c.*) The material used for insulation must be able permanently to resist variations of temperature and climatic influences.

Aerial cables can be made with any number of conductors, but probably fourteen, or at most twenty-seven, conductors are the most practical, because cables of a larger number of conductors no longer possess sufficient flexibility, and become altogether too cumbersome.

The extent to which aerial cables should be used depends largely upon the conditions of each individual system; they can, of course, be employed either for the whole of the lines of a telephonic network, or for certain distances or for portions of the network only.

It will, however, as a rule, be found most advantageous to replace certain sections only of the aerial lines, either wholly or partially by cables.

In the former case the whole of the air lines, from the central office up to a certain point, or points, will be joined into the requisite number of aerial cables, attached to simple supports, and which from these points branch off in the ordinary way. By this means the construction of supporting frames of large size is avoided.

In the latter case the mode of proceeding would be, in the first place, to construct in the usual manner a small portion of the lines starting from the central office, whilst the remainder is formed of aerial cables.

At the first point of junction, where a number of subscribers' wires branch off from the main line, the first of the cables is placed in connection with a certain number of aerial lines branching off from this point; a second cable is treated in the same way at the second point of junction, and so on; so that the main line in its whole extent is only burdened with a comparatively small number of open wires.

92. The form of aerial cable for double wires which has been found best suited to the needs of the British Post Office fairly represents the type of cable most useful for use under conditions such as we have to deal with in England.

(a.)—*British Post Office Cable.*

The conductors are composed of three strands of tinned copper wire weighing together 2 kilogs. per mile, and giving a resistance of about 45 ohms. Each conductor is covered with two coats of compounded india-rubber, not vulcanised, bringing the diameter up to ·325 centimetres, and the weight to 24 kilogs. per mile. The wires so treated are then tested carefully under water for insulation and electrification.[1] If approved, the wires are next taped with thin indiarubber-coated cotton tape laid on longitudinally, and covered with ozokerit. The wires are then twisted together in pairs, laid up in cables of the required number of wires, wormed with jute, and lapped with stout tape prepared with bituminous compound. After the whole core has received a coat of bituminous compound it is served with a coating of hemp thoroughly saturated with a well boiled gas-tar compound, over which is put the external covering of stout bituminous prepared tape and a coating of silicated

[1] *Electrification* is a phenomenon shown by insulating materials when a current of electricity is applied to them to obtain their insulation resistance. It is due to the leakage current polarising the dielectric. If the current be kept on the insulation apparently improves—rapidly at first, then more slowly—the leakage current diminishes in strength; in other words, the resistance apparently gradually increases, owing to the formation of an opposing electro-motive force in the medium, which thus acts as a liquid electrolyte. As this effect varies with time, it is usual to take a test reading for insulation after *one minute's electrification*. The rate of fall due to electrification is agreat test of the soundness of the insulating material. It varies very much with the quality of the material, and with temperature, being more marked at low temperatures. Unsteady electrification is a sign of an incipient fault in the insulation, and slow electrification, when not due to defective insulation, is an indication of good material.

compound. This forms a thoroughly reliable, durable, compact, and waterproof cable.

(*b.*)—*Felten and Guilleaume Cables.*

93. There are two types of aerial cable manufactured by Messrs. Felten and Guilleaume, of Cologne, which are worthy of special notice here. They use lead covered and so-called shielded wires. Their plan is to place and firmly press between the insulated strands one or more bare copper or steel wires. The latter are thus on the whole surface brought into permanent connection with the metallic coatings of tin-foil with which each strand is covered, and are then at each end of the cable connected to earth; so that the whole of the metallic coatings of all the strands represent one uninterrupted line of good conductivity, which, through being connected to earth at both ends, weakens the inductive effects of one strand upon another.

One form of cable, largely used by the Amsterdam Telephone Company, is known as

(*c.*)—*The Type of the Amsterdam Telephone Company.*

It consists of eighteen conductors insulated with india-rubber, and surrounded by a coating of thin lead-foil, each conductor being formed of three copper wires of ·5 mm. diameter. These eighteen conductors constructed in this way are wound round a core of seven galvanised steel wires of 1·4 mm. diameter, which serves as the earth wire.

The weight of the cable is 1,600 kilograms per 1,000 metres.

(*d.*)—*Crawford Type.*

94. This cable consists of twenty-seven conductors of copper wire ·7 mm. diameter, each of which is insulated with yarn impregnated with a bituminous compound, and surrounded or shielded with tin-foil. A copper wire of 1·2 mm. diameter, acts as a core for the three middle strands, and serves also as earth. The individual strands thus prepared are twisted together, wrapped in a band of impregnated cotton stuff, surrounded with lead, which is firmly pressed all round, and finally all are wrapped in a preservative serving treated with oxide of zinc.

The weight of the cable is 750 kilograms per 1,000 metres.

These cables are generally made in lengths of from 500 to 1,000 metres.

95. The connection of the cables with one another and with the ordinary open wires is a matter that calls for the most careful attention, and the following instructions, although made with special reference to the Felten and Guilleaume cables, will no doubt be found to be applicable and useful, for general principles at least, to other forms of cable also.

(*a.*)—*Jointing a twenty-seven stranded telephone lead-cable.*—The ends of the cables to be joined together are freed from their external covering, which is cut off, on one cable to a distance of 560 mm., and on the other to 260 mm.

The lead coating thus laid bare is well cleaned, and then at each end a nut (Fig. 80) to receive the connecting sleeve E E, fitted with discs and washers, is pushed over the longer of the bared ends.

The lead coating is then carefully cut off and removed to a distance of 160 mm. from the end, and in the same way the insulating coating is laid bare to about 145 mm. The coating of tin-foil is then removed from the single strands to about 60 mm., and the insulating coating to about 50 mm., the latter is done by scraping with a blunt knife.

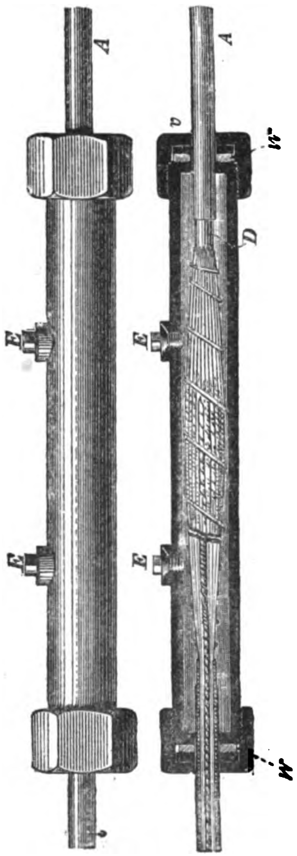


FIG. 80.

All these operations must be performed with the greatest caution, and especially the sharp edge of the cut lead coating must be carefully removed.

The copper wires thus laid bare are cleaned, and then joined together by twisting them (about four twists at each end) and soldered in such a way that the twisted places have a length of about 10 mm. The earth wires of the cable are likewise joined together by twisting and soldering, but either in front or behind the line wires to prevent the junction becoming too thick.

In a twenty-seven stranded cable, first of all the three centre wires, then the three earth wires, after that the nine wires of the middle layer, and finally the fifteen exterior wires are to be joined together.

The entire distance (DD) between the ends of the two lead coatings is about 250 mm.

The several junctions formed by the twisting of the various strands are wrapped round with insulating ribbons, until they show the same diameter as the insulating coating, and the whole is fastened by means of a string.

The twelve interior strands, after this treatment, are again wrapped round by a ribbon, to keep them separate from the fifteen exterior strands. The twelve interior wires and the three earth wires having been wrapped up together, the fifteen exterior wires are likewise twisted together, and tied up in a spiral ribbon. After this the whole place of junction is loosely tied up with a string or ribbon, and heated insulating material is poured into it until air bubbles cease to make their appearance. After this the connecting sleeve is pushed over the place of junction in such a way that the lead coating at each end will penetrate into it a distance of about 25 mm. The locking screws are now firmly tightened by hand, so that the indiarubber washer inside the locking screw surrounds the lead coating and renders it water-tight. In the figure the washer will be seen at WW; the figure on the right is a cross section of the cable within the connecting sleeve, whilst that on the left is an elevation.

After the two screws have been removed from the openings E, the sleeve is heated by means of a blow-pipe, and some insulating substance, which has been previously heated into a liquid state, is poured into one of the openings. This operation is continued until both the openings are partly filled, whereupon the screws are again inserted.

In all these operations it is most essential to exclude any trace of moisture and, above all things, to secure an absolutely water-tight junction of the cable because the impregnated texture readily absorbs moisture, and thus materially injures the insulation.

96. (*b*.)—*Connection of the cable with the ordinary wires.*—For this purpose a terminal sleeve is employed, which differs from the connecting sleeve only by having two additional cast iron flaps, which serve for fastening it to the point of attachment, and also that one of the two terminal pieces has a somewhat larger opening to accommodate a lead cable with india-rubber strands.

The construction of the terminal sleeve, as well as of the place of junction of the lead cable, with a cable of indiarubber strands, will be seen on reference to Fig. 81.

The connection of the indiarubber-covered strands with the core of the lead cable is effected in the way described above, but, for the sake of the indiarubber, neither the sleeve nor the insulating substance must be heated above 180° C. The indiarubber cable is allowed to protrude to a considerable length from the terminal sleeve, and is bent downwards, where the different strands are joined to the air lines without any tension, each junction being well soldered. Fig. 81 shows an iron or steel rope carrying a cable joined to the open lines.

97. Regarding the means of running the cables, th

method adopted in England generally is to have two stranded steel wires run side by side, and connected at intervals by loops of the same wire, simply hung across from one wire to the other. These loops form, as it were, a continuous cradle, in which the cable lies.

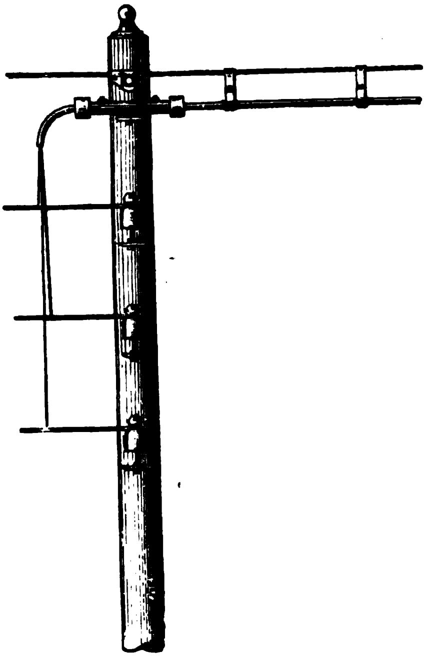


FIG. 81.

Under the Continental system the cables are fastened to suspension strands made of galvanised steel. These are shown in Fig. 81, and other contrivances used are shown in Fig. 82.

The suspending strands are stretched with a dip of about 2 per cent.

Let g be the weight in grammes per metre of the cable to be suspended, s the span in metres, p the dip (in percentage of s), x the cross-section of the suspending strand; then, if the breaking strain per square millimetre

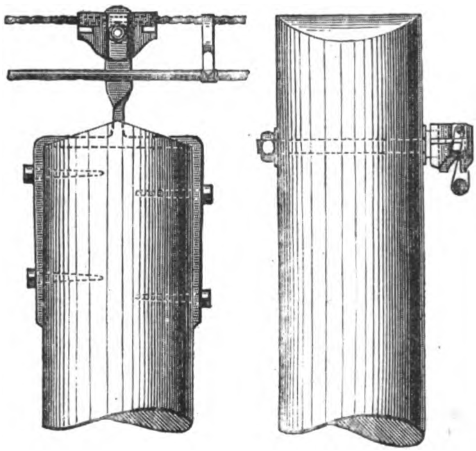


FIG. 82.

of the suspending strands is about 44 kilogrammes and the factor of safety is taken as one-fourth:

$$x = \frac{sg}{882 \cdot 52\, p - 7 \cdot 86\, s}$$

Assuming it to have been found advantageous to construct the suspending strands of seven steel wires, the cross-section of each wire will be

$$\frac{x}{7}$$

The hangers of galvanised hoop iron (Fig. 83), are attached to the cable at distances of one metre, by means of galvanised binding wire. The raising of the

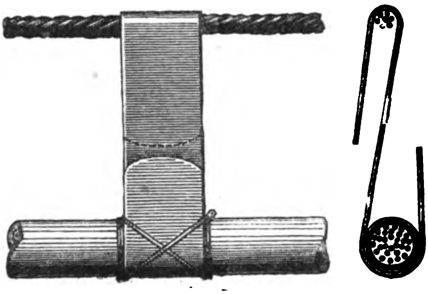


FIG. 83.

cables on to the roofs must be effected with the greatest care, so as to avoid any injury to the cable

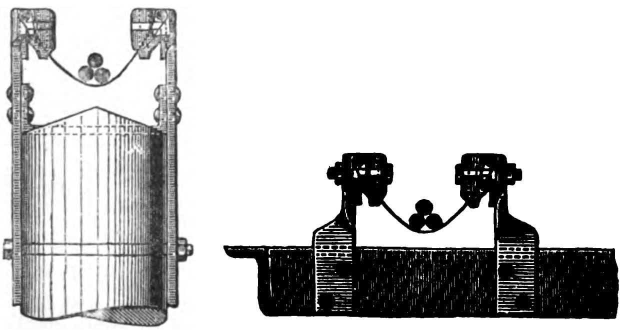


FIG. 84.

or the roofs. As the cable is pulled forward from one point of support to another the cable hangers are one after another fastened to the cable. As soon as one hanger, sliding on the suspending strands, arrives at a point of attachment, it is there detached from the suspending strands by the workman, and suspended again immediately behind the point of attachment; so that the cable during its forward motion is always carried by the hanger.

If several cables are to be used simultaneously in one section of a line the construction shown on the left of Fig. 84 is sometimes adopted for wooden supports, and the contrivance shown on the right for iron supports, each cable having a separate suspension strand.

2.—UNDERGROUND CABLES.

98. In England the telephone companies have not hitherto taken to the use of underground wires, but the Postal Telegraph Department adopts this method wherever possible, as much for economy as for efficiency.

(a.)—*The Post Office Underground Cable.*

This is, for reasons already explained (§ 83), a cable which provides a pair of wires for each circuit. It is uniformly made with four wires only, the copper conductor of each weighing 18 kilogs. per mile (1·2 mm. diameter), and being covered with best gutta percha to a diameter of about 4·4 mm. Four of these wires are laid up with a lay of seven inches, having a centre and worming of tanned jute sufficient to make the cable cylindrical. The cable is then served with a single covering of specially prepared grey linen tape.

99. Perhaps the best-known type of underground

cable used in America is that manufactured by the Western Electric Company, and known as

(*b.*)—*The Patterson Cable.*

This is composed of a group of copper conductors, each covered with two or more servings of cotton, and the whole protected by a lead pipe. The cotton is saturated with paraffin.

The exterior covering, which is composed of lead strengthened by a small percentage of tin, is a tube made separate from the core, and the latter is drawn into it. The size of the tube is not limited by the size of the core. It is made larger, sometimes by as much as ¼ in., and the space thus left is afterwards filled with melted paraffin, under heavy pressure.

The insulation of this material is very high, and it will not vary as long as the lead covering remains uninjured.

The inductive capacity of paraffin is well known to be low, but this is said to be lowered by at least 15 per cent. by the process of manufacture. So that, by laying the wires loosely together and pressing prepared paraffin in between them, the dielectric obtained has a lower inductive capacity than if the whole space were filled with cotton, gutta percha, or any other similar insulator.

The splice protection used on aerial and underwater cables, and also on underground cables where the arrangements of man-holes will allow, is similar to the one used for the Felten and Guilleaume cable, § 95. The lead pipe sleeve which covers this splice is drawn over the end of one of the two sections, and after the wires are spliced together, it is drawn back over them and secured on the cable pipe at each end by a "wiped" solder joint, generally known as a plumber's joint. When it is finished, the cable is heated on each side of the splice to melt the paraffin, which expands in melting, and,

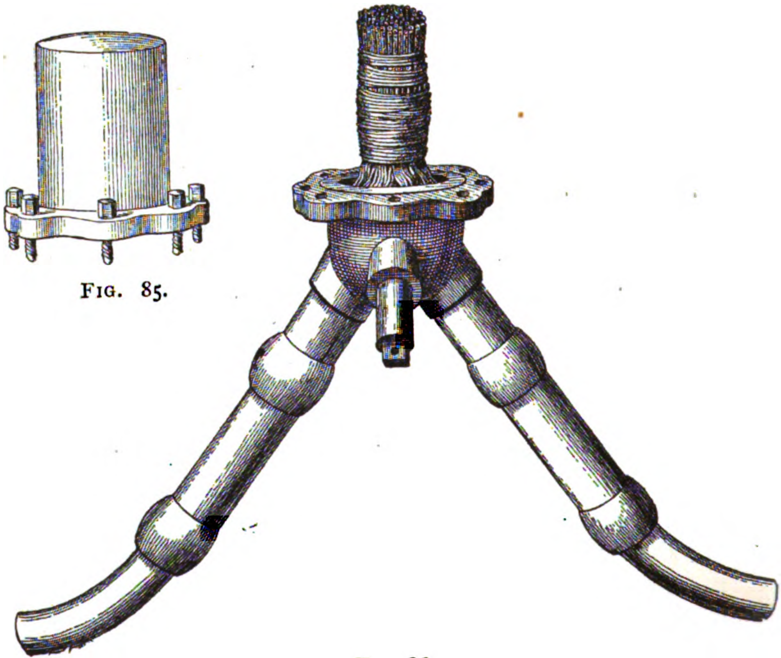


FIG. 85.

FIG 86.

rushing into the splice, affords a safeguard against imperfections in the pipes and joints.

Fig. 85 is another form of splice for use in underground systems where the other style could not be used, or where a few wires are required to be taken from the cable at different points along the route. In very long cables this splice has the advantage that it may be opened at any time for locating faults.

Fig. 87 shows a test box which is very generally used in offices to connect a cable to the wires leading to the

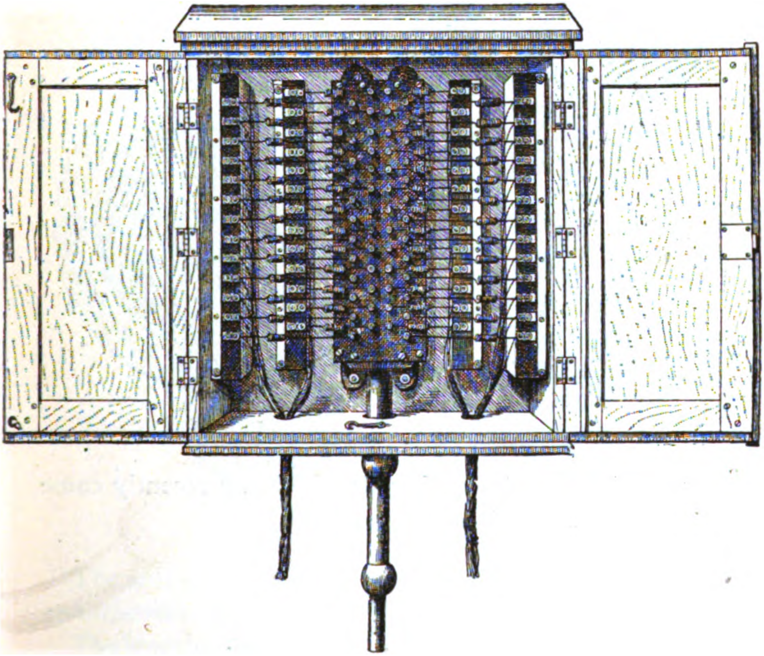


FIG. 87.

apparatus. The terminals are fixed on ebonite bases to secure insulation, and the box is thoroughly air-tight; but it is sometimes filled with paraffin to insure against any possible imperfections in the rubber backing under the iron face plate.

Fig. 88 shows a hanger for aerial cables.

Fig. 89 gives an end view of a 100-wire underground cable.

The whitening around the core is the paraffin filling, and the outer ring is the composition pipe.

FIG. 88.

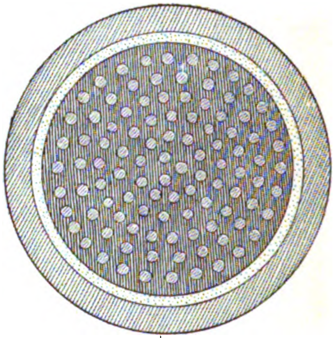


FIG. 89.

100. Another form of cable which has recently come into use in the United States is

(c.)—*The Waring Cable.*

The conductors are of copper, covered with cotton and insulated with a heavy distillate of petroleum and encased with lead under great pressure. The advantages claimed for this insulating material are, that it is not liable to disintegration or deterioration; it is an exceedingly refractory substance; and the surrounding or the internal temperature may be raised to the point of fusing the leaden casing of the cable, or the raising of the conductor to a white heat, without affecting the resistance of the insulation, or even injuring it—much less destroying it.

Where a great number of conductors are required in a minimum space, the so-called "bunched" cables, of the form shown in Figs. 90 and 91, are produced.

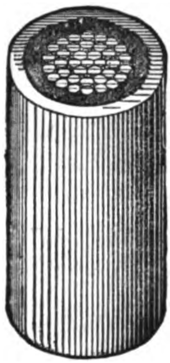


FIG. 90.

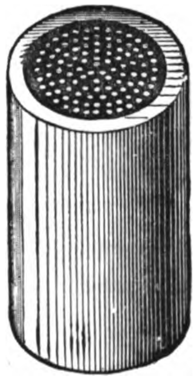


FIG. 91.

The anti-induction cable, constructed on the principles enunciated in § 91, has the form shown in Figs. 92 and 93.

The lengths are united by a simple joint as follows:— The cable ends are first stripped of the lead, the insulation removed, and the wires substantially joined and soldered. Each wire joint is then wrapped with insulated tape, and this served with strips of lead to preserve the metallic continuity of the casing. A sleeve of lead pipe, previously slipped over one of the ends, is then brought over the joint, both ends dressed to fit the cable, and solder-wiped joints made in the way indicated by Fig. 94.

The sleeve, being tapped near the centre, is then filled

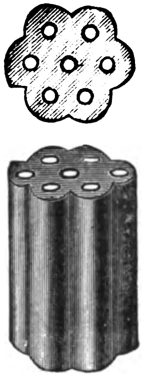


FIG. 92.

FIG. 93.

with insulating material and closed. Where there is likelihood of a tensile strain in laying the cable (as in

FIG. 94.

deep water), after reaching the point of placing on the sleeve, as above described, the connection is made by a single solid plumber's joint, as shown in Fig. 95.

FIG. 95.

Laying the cable is performed with facility, a trench being dug about two feet deep, an open trough or box is laid on the bottom and a reel of cable, with an axle turning through its centre, mounted on wheels, is drawn along paying off the cable into the trough as it moves along (Fig. 96).

The methods of *looping*, *branching*, and *spreading* are represented respectively in Figs. 97, 98, and 99, and it will be seen that these cables offer great facilities for

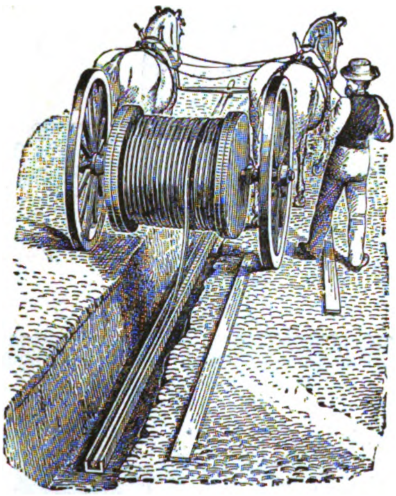


FIG. 96.

reaching any particular conductor or for leading it in other directions from the main cable, without severing the latter or disturbing the remaining conductors. The sharp or square edge, formed on one of the ribs, as shown in Figs. 92 and 93, enables one to find any conductor; by counting to the right or left any desired conductor can be selected without disturbing the others. Each wire is numbered from this edge.

Fig. 100 represents a cable box on a junction pole, showing the connection from an underground cable to aerial lines, as adopted by the New York Fire Department.

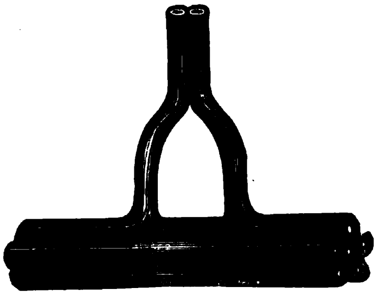


FIG. 97.

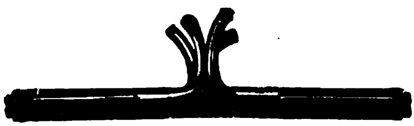


FIG. 98.

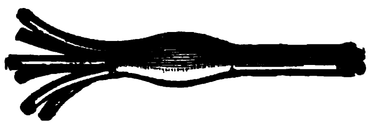


FIG. 99.

(*d.*)—*Brooks's System.*

101. Mr. David Brooks, of Philadelphia, one of the telegraphic veterans of America, proposed in 1881 to place a cable of cotton-covered conductors in an iron or lead pipe, and to maintain this pipe full of liquid oil, which should have a steady but slow flow, so as to prevent or close up any faults that might arise. His plan

was tried, and is still in use, in London as well as in Philadelphia, Chicago, and New York. His object

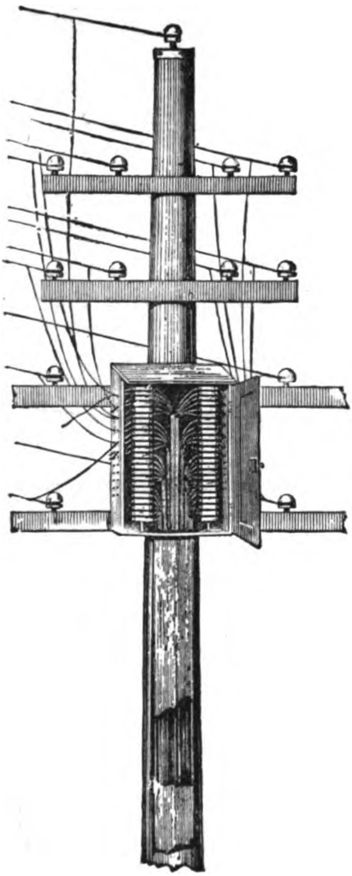


FIG. 100.

was to compress the largest number of wires into the smallest possible space. He obtained very high insulation (nearly 20,000 megohms per mile), with low capacity (about ·2 microfarads per mile). At first he used light paraffin oil, but lately he has been using heavy resin oil, and a mixture of resin and resin oil, which, having a greater specific gravity than water, expels any water from the pipe that may have found its way there by accident or design.

(*e*).—*Berthoud-Borel Cable.*

102. The insulating substance consists of cotton yarn saturated with a mixture of resin and oxidised linseed-oil. Cotton stuff saturated with the same insulating

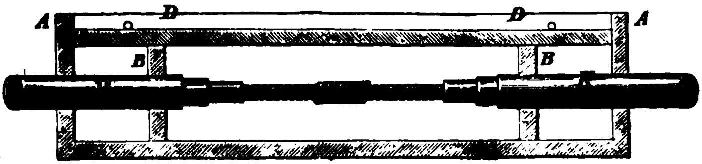


FIG. 101.

material is wrapped round the conductors forming the cable, and, finally, a lead cover, consisting of two layers, pressed round the whole.

The resistance of each conductor of a cable consisting of twenty-seven conductors of stranded copper wire (three wires of ·5 mm. per strand) is 30 ohms per kilometre; the capacity ·15 microfarad. One thousand metres weigh 1,725 kilogrammes, and cost 3,000 marks (shillings).

The following is the method adopted for jointing, and leading off from a single core cable:—The cable K K, after having been freed from the different covers of lead and insulating material, in proper gradations, as represented in Fig. 101, is inserted through lateral openings in an iron box, and the two ends are pushed together in the centre of the box. The ends are then sloped off, as is customary in the soldering of ordinary cables, wound with fine copper wire, and finally quickly soldered in the usual way. The pieces B B serve for the support of the cable. The interior space is then filled by pouring in a strongly heated mass of insulating material (resin and linseed oil). The two small chambers on the right and the left of the box are filled with thick melted tar. Finally the cover D D is put on, and firmly pressed against the box by means of two pins entering through the sides of the box. The filling of the box must be effected in such a way that the cover when

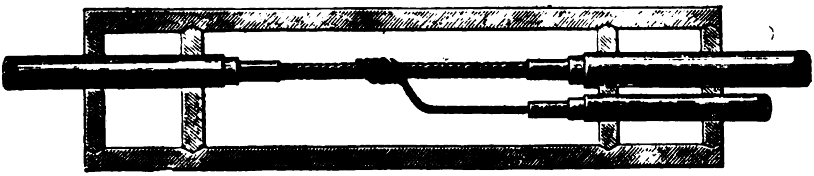


FIG. 102.

tightly fastened presses together the insulating mass which has been poured in in excess. After the cover has been put on as described, the free space formed by the depression of the cover is filled up with thick tar.

If a cable of several cores has to be joined, a box of larger dimensions is employed, and within it the individual cores are led through bore holes of inserted ebonite discs, and thus kept apart.

The branching off of a core is effected in the joint-box in the manner shown in Fig. 102.

103. It will be seen that the practice of underground work adopted in each country is very much the same.

In England, where underground systems have existed since the first introduction of telegraphy in 1837, gutta percha remains paramount as an insulating medium for subterranean and submarine purposes, but exposed to the changes of temperature and moisture of the air it rapidly deteriorates. Here, for aërial purposes, india-rubber is more generally used, and is very durable. In America, where underground work has hitherto been tabooed, experiments are being made with other materials, more especially with the products of that rich and abundant oil—petroleum—that has become such a grand industry. Paraffin is used by some, but the most promising material is that heavy distillate of petroleum, that is used in the Waring cable (§ 100). Oils are used by others, and, when mixed with resin, they acquire a very high insulating efficiency. Lead-covered cables are being re-introduced everywhere. It is interesting to note that the lead-covered cables buried in the streets of London, laid down in 1844, are identical in appearance and construction with those now being used. Lead is, however, very liable to damage when buried unprotected in the earth. Some soils act upon it chemically, and destroy it. It should, therefore, always be protected. It is better to place a lead-covered cable in a trough, and to fill the trough with asphalte pitch or bitumen. This is expensive, but it is secure.

The only really effective mode of getting over the disturbances due to induction between wire and wire, is the metallic circuit system. The British Post Office and the French Telephone Company are the only Administrations that have decisively adopted this plan. The principal objection raised is that of expense, but this disappears on investigation, for, while the prime cost may be higher, the improved service leads to a largely enhanced income. When the absolute perfection of working of a metallic circuit system is experienced, it is remarkable that any other system ever should be contemplated. Human nature is very loth to admit that it is wrong. Those who have matured the one wire system do not like to sweep away their cherished plans, but as the systems grow, it seems impossible to conceive that they can continue to work effectually such an imperfect plan. The use of the earth is essentially bad, and it admits an infinity of troubles. The double wire system must infallibly survive.

CHAPTER XI.

AUXILIARY APPARATUS USED IN THE INSTALLATION OF TELEPHONE STATIONS.

104. Besides the telephones themselves, which have been described in principle in previous chapters, and the general arrangement of which will be dealt with in Chapter XII., there are several auxiliary details which are essential to the working of a telephone system.

(*a.*)—*Call Bells with Current Interrupter, or so-called Trembling Bells.*

On a wooden plate P (Fig. 103), which is fastened either to the top or the bottom of the telephone case, is an angular iron piece *r*, which carries the dome G and the electro-magnetic system *e*.

A brass plate *t*, insulated from the angular piece *r* by means of ebonite, is fixed to its shorter limb, and an enlargement of plate *t* carries a spring *f*, provided with a platinum contact *c*, and regulated by the adjustment screw *s*. The latter is fixed in position by the lock nut *m*. The spring *f* presses with its contact *c* against a contact on the lever *k* carrying the armature and hammer, the lever being fastened to one limb of the angular piece by means of a flat spring *b*. The object of spring *b* is to bring about a rapid vibration of the hammer *k*; its position can be slightly altered by a small screw *d*, and the clapper can thus be more or less strongly pressed against the spring *f*.

The line wire is connected to the insulated piece *t*,

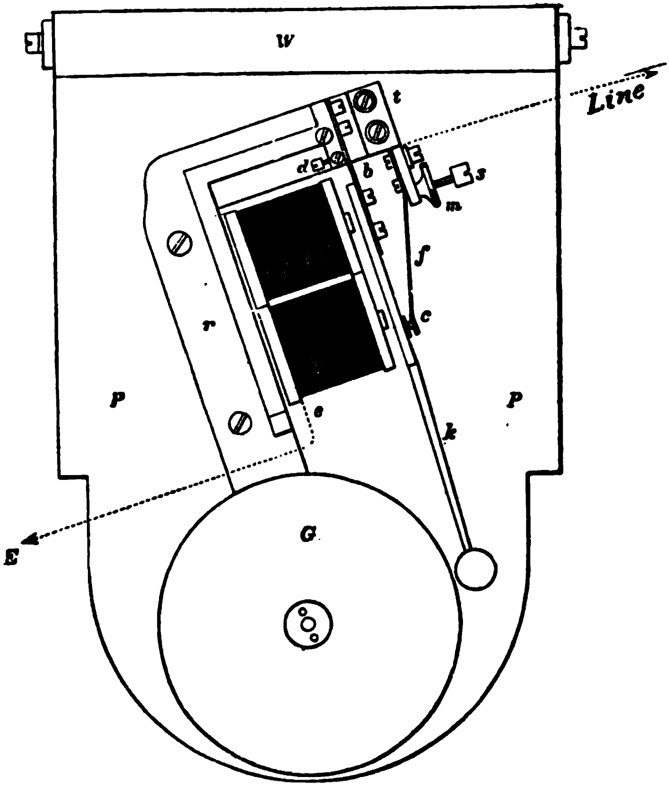


FIG. 103.

whilst the angular piece, and consequently the clapper fixed to it by spring *b*, is in connection with one end of the coils of the electro-magnet, the other end being connected to earth.

The calling current which arrives through the line wire flows through the insulated piece *t*, the spring *f*, the contact *c*, to the armature *k;* thence through the flat spring *b*, the angular piece *r*, to the electro-magnet, and through its coils to earth. As soon as the electro-magnet is excited, it attracts the armature *k*, the contact at *c* is broken, the current is interrupted, the armature recedes through the action of spring *b*, again presses against contact *c*, thereby closing the circuit; so that the play can begin anew. The hammer, therefore, in its rapid vibrations beats against the bell G as long as a current is sent into line and produces a trembling sound.

To produce an effective call, the call stud at the sending station must be kept pressed for a few seconds.

(*b*).—*Call Bell with Annunciator Drop.*

105. It is often desirable that a call from a distant station should actuate not only the bell attached to the telephone case, but also a second one, placed in some other room of the house, and should ring this second bell until somebody appears at the telephone and interrupts its action.

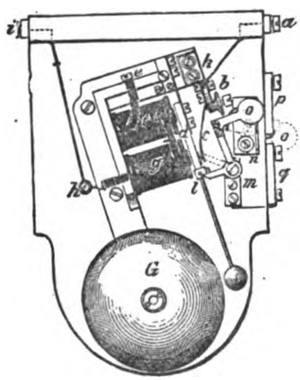


FIG. 104.

For this purpose the call bell shown in Fig. 104 is often used; it is similar to the previous instrument, but is provided with an annunciator drop. To the armature of the call bell is fastened an insulated check-pin *l*, against which abuts an articulated lever pivoted about *m*, and provided with a small finger; the other extremity of the lever carries the annunciator drop *o*. If the armature is attracted by the cores of the electro-magnet, the check-pin moves away from the finger of the lever, and this latter assumes the position indicated by dotted lines; so that the indicator drop projects through an opening at the side of the bell case. When the articulated lever descends, its upper arm falls upon the insulated contact *n*, which is connected to terminal *p* outside the case, whilst the metallic piece, to which the lever is fastened, communicates with terminal *q*. Between *p* and *q* the second call bell, with its battery, is inserted, so that its circuit is closed as soon as the lever goes against *n*. The second bell, therefore, rings as long as the lever is in the dotted position, whilst the other bell sounds only as long as a current flows through the line.

The lever is replaced in its original position, and the second call bell cut out of the circuit by pressing a stud fastened to the case, but not visible in the figure.

A special switch is generally inserted in the circuit of the second bell, so as to prevent the bell from ringing if a call should be made after certain hours.

(*c.*)—*Call Bell without Current Interruption (with Automatic Cut-out.)*

106. Call bells with current interruption frequently suffer from the defect that the contact between the spring and the armature becomes faulty, and the circuit is thereby broken; a further drawback is that

two call bells cannot be placed in series on the same circuit.

Hence call bells with automatic cut-outs are now very frequently employed. An apparatus of this kind is represented in Fig. 105. At the lower extremity of the armature *d* a spring *l* is fastened a short distance apart and sideways from the rod carrying the hammer. As soon as the armature is attracted by the electro-magnet the spring *l* presses against the contact-screw *m* fixed to the metallic piece *h*.

The line terminal *a* is joined to the body of the call bell, to which is also fastened one end of the electro-magnet coils, whilst the other end is in connection with the metallic piece *h*, which is in direct connection with the other terminal *i*. The current path is from *a* to *c*, through the electro-magnet coils to *h*, and thence to *i* and earth or return wire. The armature *d* being attracted by the magnet cores, contact is made between *l* and *m*. The coils are thereby short-circuited, the current passing from *a* through the armature to the spring *l*, the contact *m*, and thence to the terminal *i*. The electro-magnet is thus rendered inactive, and the spring armature returns to its original position, so that the current, on the contact between *l* and *m* being again broken, must take its former path through the coils and attract the armature. In this way a rapid move-

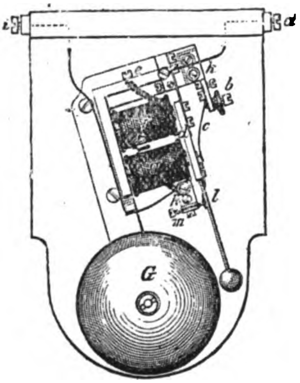


FIG. 105.

ment of the armature, and consequent oscillation of the hammer, is effected. The spring *c* which presses against the upper surface of the armature, and whose tension can be altered by the screw *h*, serves for the regulation of the armature. The contact of the short circuit spring can be regulated by the screw *m*.

The call bells used in telephony generally have a resistance of from 100 to 150 ohms, and require a current of at least 5 milliampères.

(*d.*)—*Alternating Magneto Call Bells.*

107. Where the call is effected by alternating currents, the call bell is of special construction. Two domes are

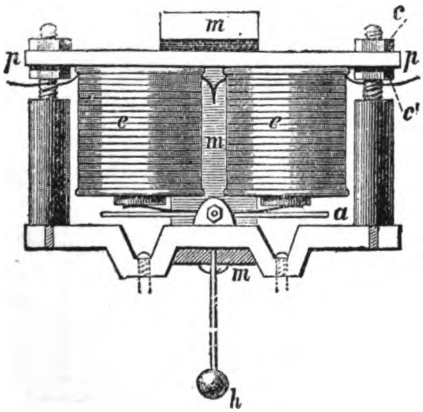


FIG. 106.

provided, so that both the current impulses, the positive as well as the negative, can be used for attracting attention.

One form (Fig. 106) consists of two electro-magnets *e*, an armature *a*, and a polarising magnet *m*. The hammer *h*, which is fixed to the armature, can beat against the two gongs. The sensitiveness of the bell is considerably increased by not allowing the polarising magnet to touch the pole-piece of the electro-magnet, but placing it opposite this latter at a distance of about 5 mm. The adjustment of the armature can in this case be very accurately arranged.

MAGNETO SIGNALS.

108. Magnetic call signals have of late years come greatly into favour for telephonic purposes. They

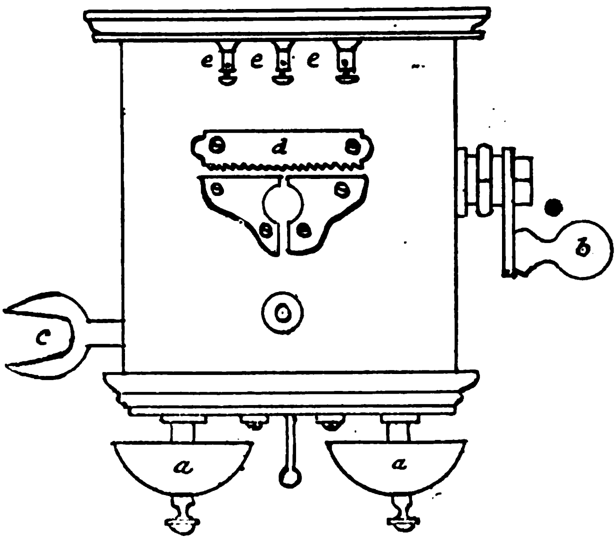


FIG. 107.

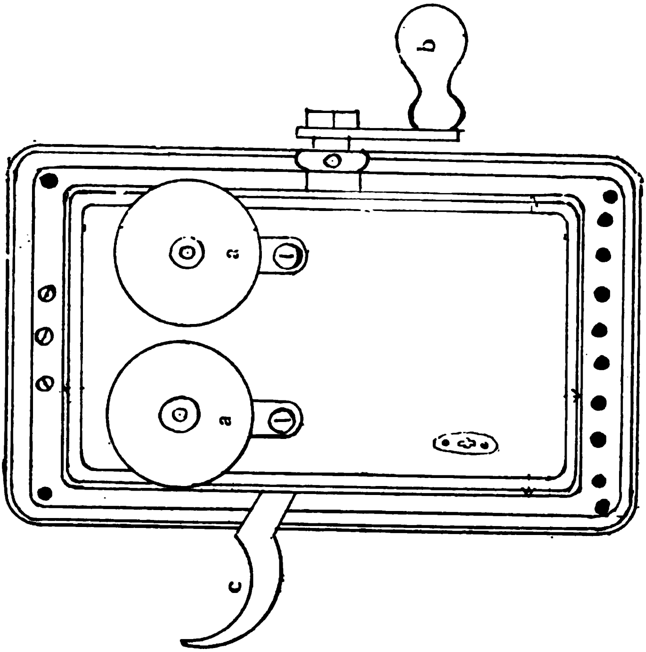


FIG. 108.

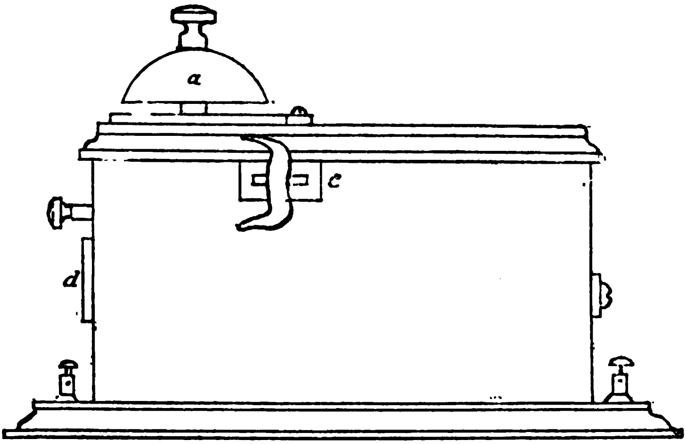


FIG. 109.

doubtless furnish a very convenient source of electric energy; but some administrations—notably the British Post Office—considering that the adoption of the microphonic transmitter already entails the employment of a

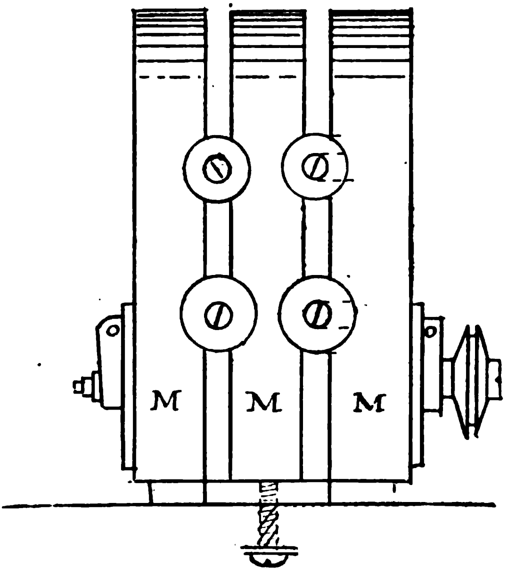


FIG. 110.

battery, and for other minor reasons, have not adopted them.

The first form of these calls was similar to an ordinary medical magneto-electric machine, but this was soon superseded by the Siemens' armature, which has since been adopted by all manufacturers. This armature, by means of a winch handle, is made to revolve in a strong magnetic field. The alternate currents generated by the machine, when the handle is turned, are conveyed to the line, and ring the call bell at the distant station.

(*a.*)—*Ordinary Magneto Call Signals.*

109. Figs. 107, 108, and 109 represent respectively a

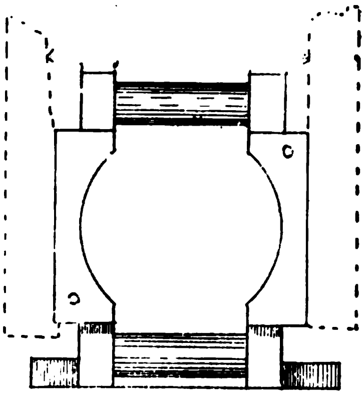


FIG 111.

plan, a front view, and a side view, of a Williams' magneto call-box, as used by the Swiss Telephone Administration. It is not essentially different from other magnetos as used by other telephone administrations.

a a are the domes of the call bell, which is described in the preceding section ; *b* the winch handle for turning the armature of the magneto-electric generator placed inside the box, and described further on, *c* the hook of the automatic switch for the suspension of the telephone, and *e e e* the terminals for making connection with line, earth, etc.

Fig. 110 gives a side view of the magnetic inductor. The three magnets marked M must be of great hardness and should, when joined together, carry a minimum weight of 1,500 grammes.

The pole-piece, shown in Fig. 111, is joined as close as possible to the magnets, and the interior hollow has to be worked with great care.

Figs. 112 and 113 show the core of the armature before winding, and the friction disc F.

The core of the armature must be of the softest iron; its cylindrical surface must be worked most carefully, and the whole must be centred as accurately as possible on the shaft of the friction disc.

The resistance of the armature windings must not exceed 1,000 ohms. In most other types of magnetos, however, this resistance is kept lower. One end of the wire of the armature is soldered to a pin, *a*, which is in direct connection with the metallic mass of the armature, and the other end is soldered to the pin *b*, which is insulated from the shaft of the armature, and is in metallic connection with the pin *d*, also insulated from the shaft by the ebonite tube *e*.

The friction disc F (Fig. 112) is made of ebonite or vulcanised fibre, and gears with the driving disc shown in Fig. 114, which gives a side view of the whole of the friction gearing and the driving crank. The two sides of the driving disc D are made of hard elastic sheets of brass of ½ mm. thickness; they are independent of one another, and are kept together by six brass screws.

There is an automatic arrangement at *c* which, when the handle is turned, breaks the short circuit in which the armature coils are placed when the instrument is at rest. This arrangement is shown at *i* in the diagram (Fig. 115). In the Gilliland magneto it consists of a spring lever carrying a contact pin.

110. With regard to the form of gearing, it may be remarked that toothed wheels were at first adopted, but were soon abandoned in favour of less noisy contrivances—rubber band and metallic friction gearing, as shown above.

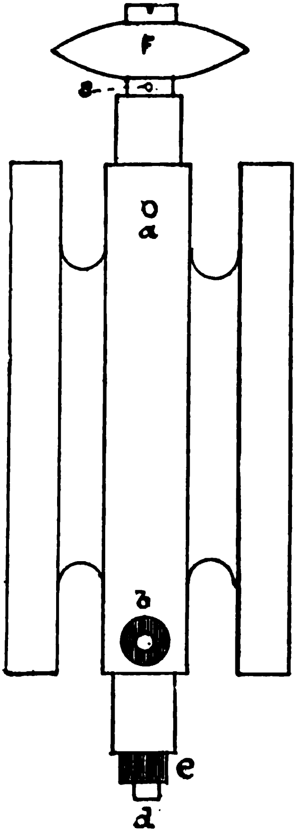


FIG. 112.

The *Gilliland* magneto had a small metal driving-wheel interposed between two small discs which formed the driven wheel. *Williams* about the same time adopted the double plate driving-wheel, which engaged a single driven wheel of some insulating material, as describe above. Others have adopted and continue the rubber band as well as the cut gear.

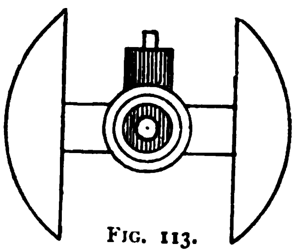


FIG. 113.

The cut gear has recently been considerably improved so as to be as noiseless as possible, and there is no doubt that it is the best form for reliability and durability.

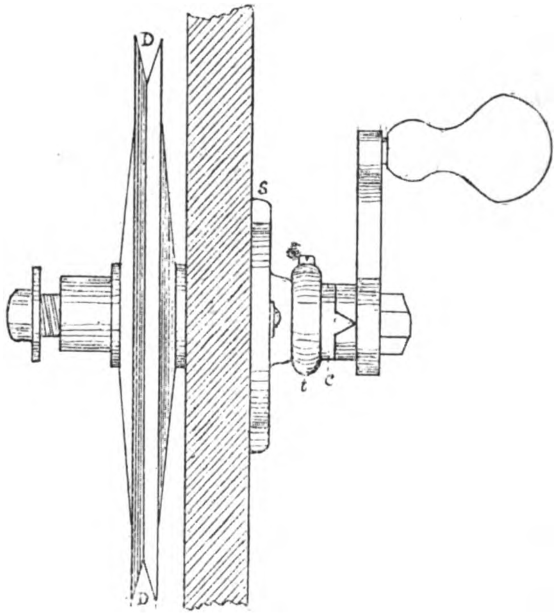


Fig. 114.

Fig. 115 is a diagram of the wire connections of the magneto call.

A good magneto inductor ought to ring the call bell through 20,000 ohms (10,000 ohms is considered ample, as a rule) external resistance, the crank being turned moderately fast; and, on the other hand, the armature of the call bell must not stick to the poles of the

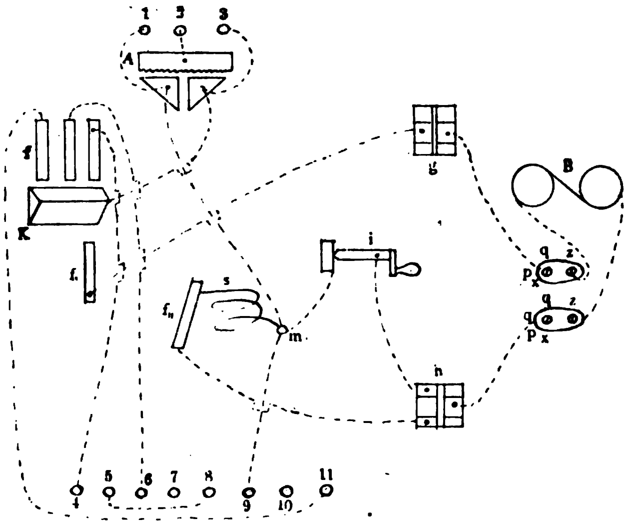


FIG. 115.

electro-magnet, even when the external resistance is zero.

(*b.*)—*Abdank Magnetic Call.*

111. This signal transmitter is shown in Fig. 116, and consists of a horse-shoe magnet mounted on a cast-iron socket. To a bracket fixed on the socket is attached a spring, which carries at its other extremity a flat coil consisting of a soft iron core and a large number of turns of fine copper-wire. One of the extremities of the wire communicates through the body of the

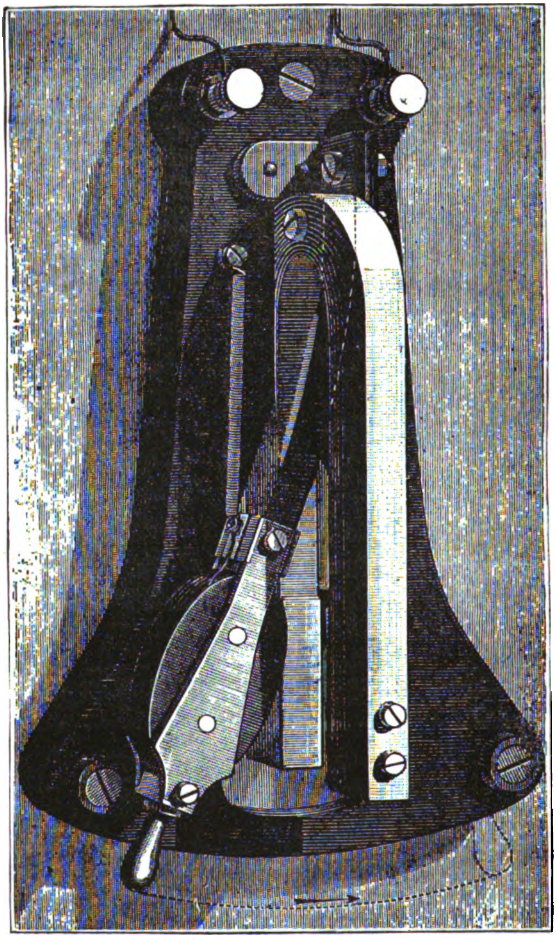


FIG. 116.

apparatus with one of the terminals, whilst the other extremity is connected by means of a spiral spring to an insulated screw, and thence to the second terminal.

A handle attached to a frame, into which the coil is fitted, enables one to pull the coil to either side of the magnet, and on letting go the handle a rapid oscillatory motion is imparted to the coil. During this motion the magnetism of the iron core varies constantly, and the windings of the coil cutting the lines of force of the magnet, a series of alternating currents are induced in the coil.

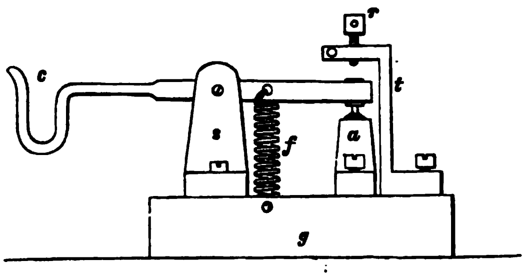


FIG. 117.

THE AUTOMATIC SWITCH.

112. Where both transmitter and receiver are magnetic telephones, the switch has the general form indicated in Fig. 117, and is so designed that when the telephone is idle the bell is in circuit, but when speaking is going on the bell is cut out.

A brass stand, mounted on a base board, carries a lever, one extremity of which is bent in the form of a hook *c*. This hook projects through the front board of the telephone case, and on it is suspended the telephone with its flexible conductors. The spiral spring *f* holds the straight end of the lever against the contact *a*, as long as the telephone is *not* suspended to the hook. As soon, however, as the telephone is suspended, by its weight it pulls down the lever, whose straight end is then pressed against the contact screw *r*.

The call bell can sound only when the lever presses against the contact *r*, and the telephone must, therefore, be always suspended to the hook when it is not in use.

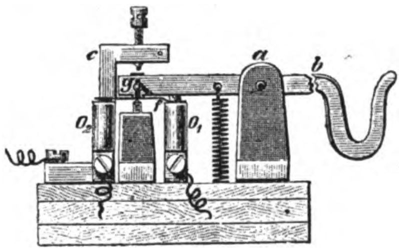


FIG. 118.

113. Where, as is generally the case in this country, a microphone transmitter is employed, on the removal of the telephone from the hook, the primary circuit of the induction coil must be closed, and the construction of the automatic switch is, therefore, modified, as shown in Fig. 118. Two small brass columns, o_1 and o_2, are mounted on the foundation-plate; o_1 carries a very flexible steel spring *f*, whose extremity stands close above o_2, and comes into metallic contact with it on being depressed. This depression of the spring is effected by a pin *g* of insulating material fastened on the side of the lever; as soon as the telephone is taken

down from the hook, this pin presses against the spring *f*, and places it in contact with o_2.

LIGHTNING PROTECTORS.

114. In order to protect the telephonic apparatus against damage by lightning, it is usual to provide each set with a lightning protector. These generally are of

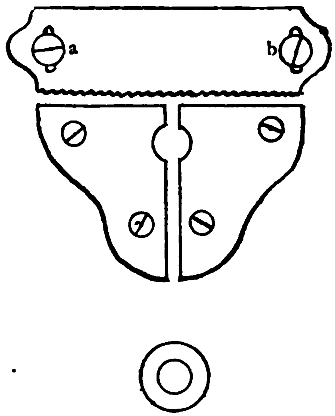


FIG. 119.

the very simplest description, that ordinarily used being of the form shown in Fig. 119 and in position in Fig. 107.

It consists of a brass plate with sharp saw-teeth in connection with the earth fixed near to two other plates which are connected to the lines. There are slots at *a* and *b*, to enable the distance of the long brass plate from the two triangular pieces to be adjusted.

As a matter of fact, however, telephonic apparatus is not very liable to damage from this cause in England, and when damage is done it is generally very slight.

This liability is practically reduced to *nil* when double wires are used, as the circuit then offers an easy passage to earth for the lightning discharge: consequently the British Post Office finds it quite unnecessary to protect their ordinary telephone circuits. Where protection does seem desirable, as in the case of single wires, the Post Office pattern of lightning protector, shown in Fig. 120, is fitted up.

This consists simply of two circular brass discs having perfectly flat faces, which are tinned. Between these two faces is placed a disc of mica with three perforations

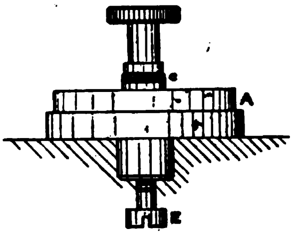


FIG. 120.

around a centre hole. The upper (or front) plate is fixed to the lower by means of a terminal, insulated from A by an ebonite collet *c*, which is faced with a brass washer, between which and A the line wire is clamped. The protectors are fixed upon bases singly or in groups, and the earth connection is made to the back screw E.

The figure is two-thirds full size.

115. The German Postal Administration has introduced for telephonic purposes an elaborated form of the reel or tube lightning protector, which is deserving of special notice. It certainly possesses several features of interest.

In the apparatus represented by Fig. 121, three brass cylinders m_1 M, m_2, insulated from one another, are fastened together. The middle cylinder M is directly soldered on the spindle $s\ s_1$, while its two extremities m are turned down, so as to form barrels of somewhat smaller diameter than the centre piece. On these pins a silk-covered wire of ·1 mm. diameter is wound.

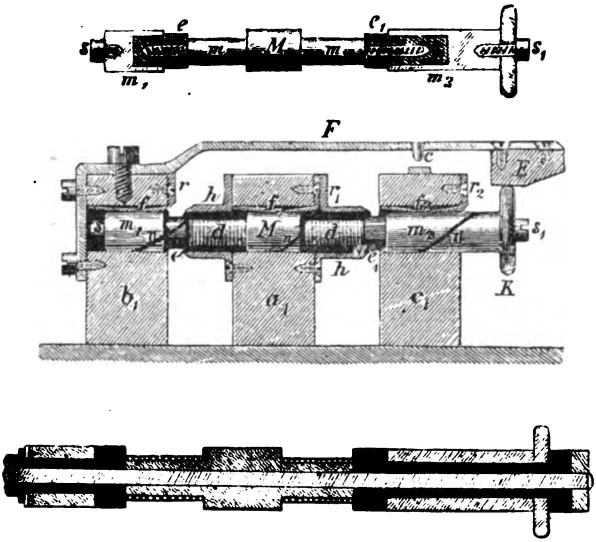


FIG. 121.

The pieces m_1 and m_2 are insulated from the spindle and from M by means of ebonite collars. The centre piece M, as well as the ebonite collars, have on their surfaces a spiral-shaped groove, into which is inserted the wire d, wound on M. The two extremities of this wire are soldered to the pieces m_1 and m_2, which are thus brought into electrical connection, whilst the cylinder M is insulated from them by the silk-covering of the wire. The spindle is inserted into three brass blocks a_1, b_1, c_1, in which it fits accurately; good electrical connection is further ensured by the metallic springs *f*, which exercise a certain amount of pressure against the cylinders m_1, m_2, and M. The left-hand block, b_1, is connected to the wire leading to the apparatus, the right-hand one, c_1, to line, and the centre one, a_1, to earth. The line wire goes from the right-hand block, through the silk-covered wire to the left-hand block, and thence to the apparatus. If too strong a current passes from the line to the lightning protector it must pass through the silk-covered wire, which it will melt or heat so as to destroy the silk covering, and thus pass to M, and thence to earth; the circuit of the apparatus is at the same time broken by the melting of the wire, and the apparatus itself is thus secured against damage.

In order to restore working order at the station, the spindle must be changed after the fusing of the wire. This is done by simply taking the spindle out of its bearings, and this operation would leave the instrument disconnected were it not for the following changes of contacts which are brought about by the operation itself:—

To the left-hand block, b_1, a brass spring F is fastened which carries a platinum point *c*, and when the spindle is withdrawn this rests against a small platinum disc on the right-hand block, c_1. The two blocks b_1 and c_1 are thus directly connected together, and the line goes direct to the apparatus. If a new spindle is now inserted, the disc K, which is fastened to it, raises the ebonite block E fixed to the spring F, interrupts the platinum contact, and places the protecting wire of the new spindle in circuit.

CHAPTER XII.

ORDINARY TERMINAL STATIONS.

(*a.*)—*With Microphone Transmitters.*

116. Fig. 122 gives a general view, and Fig. 123 (reproduced from p. 65) shows the connections of the Gower-Bell Telephone as used by the British Post Office.

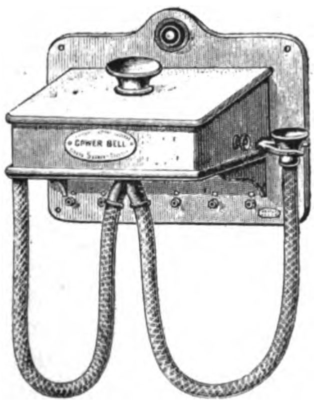


FIG. 122.

In connection with this we will follow out the general principles of the arrangement of the parts of a telephone.

K is a small key pivotted at its lower end and made to play between two contact points. The lever itself is connected to line, and the upper contact of the key is connected to one pole of the call-battery; the other end of which battery is connected to earth or to the return line, as the case may be. If now the lever of K is brought into connection with the upper contact by depressing the small ivory press-button at the top of the instrument, a current will pass to line.

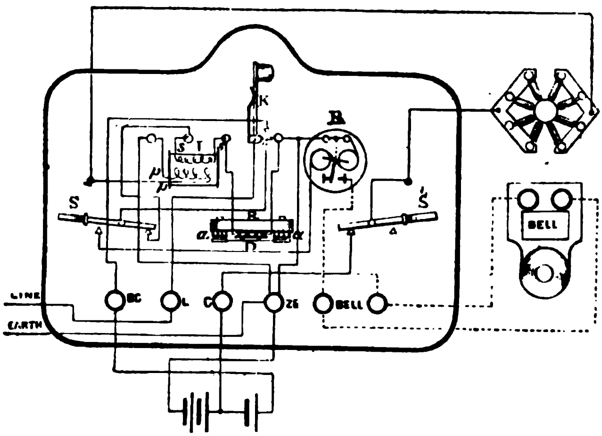


FIG. 123.

The lower contact of K is connected to the axis of the left-hand switch-lever S, the longer end of which latter, as well as that of the right-hand switch-lever is normally kept depressed by means of the hearing tubes, as shown in Fig. 122.

If, when this is the case, a current is sent from line it passes by way of terminal L, key K, switch lever S, and its front contact through the coils of the relay B to earth or return line, thus actuating the relay and causing the bell to ring. When this call has been acknowledged by depressing the ivory button as described above, the hearing tubes are removed from their positions of rest in the forked ends of the switch-levers S, S′, and the speaking and hearing parts of the telephone instrument are ready for use. This practically automatic change of connection is effected by means of two spiral springs which, on the removal of the hearing tubes, bring the switches S, S′ into the positions shown in Fig. 123. The right-hand lever joins up the microphone and the primary wire of the induction coil with the left-hand portion of the battery (two Leclanché cells), while the movement of the left-hand lever disconnects the relay from the line and joins in the telephonic receiver and the secondary section of the induction coil.

There is, as already stated, no essential difference between the general arrangement of the Gower-Bell and any other complete form of microphonic telephone. The construction of the microphone, for instance, will of course have a direct bearing upon the shape of the instrument, some microphones requiring to be fixed perpendicular, and others to be more or less sloping; and again where separate receivers are used, instead of a fixed receiver with tubes as in the Gower-Bell, it is usual to combine the switches upon one lever. Some of the different forms which these complete instruments take may be seen from the illustrations in a previous chapter. (Chap. VII).

The mountings are practically the same wherever, as in this country, a microphonic transmitter and a magnetic receiver are employed.

(*b.*)—*Magnetic Transmitter.*

117. In this case, which is very rarely used, the arrangement is as represented by Fig. 124.

In order to make a call the button *a* is pressed so that the contact spring *f* touches the contact *k*. Hereby the battery B, one of whose poles is to earth, is connected

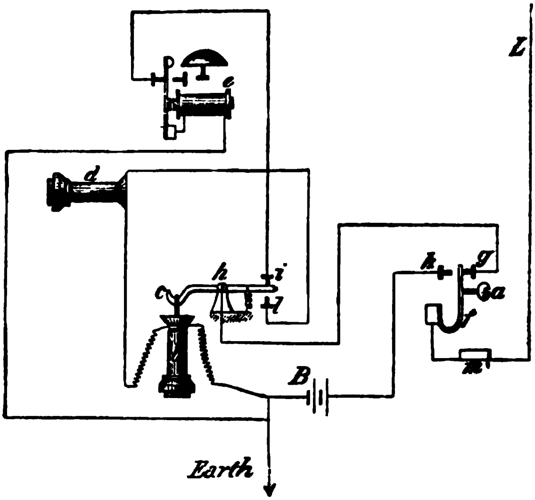


FIG. 124.

to the line L, and a current flows through *k*, *f*, and terminal *m* into the line L.

In a similar way, if a call is received, the current coming from the line L flows through *m*, *f*, contact *g*, and, through the axis *h* of the automatic switch, to the lever and contact *i*, and, finally, through the call bell to earth. The call bell, therefore, rings, provided the telephone *b* is suspended to hook *c*, so that the current can pass directly to the call bell. If the telephone is not suspended to the hook the call circuit is broken.

After having given the signal and received a similar signal back, the telephone is unhooked, and thereby the contact at *i* is broken, whilst it is made between the lever and *l*. The induction currents generated in the telephone which is used as a transmitter, flow through the coils of the two telephones *b* and *d* (one conductor of *b* is to earth), and through *l*, *h*, *g*, *f*, and *m* into the line. In a similar manner the induction currents sent from a distant station reach the telephones. Both telephones being in circuit, they can be used *both for speaking and for hearing*.

In order to hear quite distinctly, one ear is placed against the telephone which is fixed horizontally in the case, whilst the other telephone is held against the other ear; it is shown by Fig. 131 p. 206; in this way noises coming from outside are effectually shut off. As a rule, however, the telephone suspended to the case is used for hearing, whilst the instrument fixed to the case is used for speaking, so that no interruption occurs in the conversation.

CHAPTER XIII.

INTERMEDIATE STATIONS.

118. WHEN more than two stations are in communication upon one circuit, it is often desirable or necessary that the user should be able to divide the circuit at will at one or more points. Thus, if there are three stations, it may be required that when any two are communicating, the third, although still able to signal for attention, shall not be able to interrupt or overhear the conversation of the other two. Again, if there are more than three stations, the circuit should be so arranged that if two at one end of the circuit are in communication, it shall not prevent two stations, both nearer the other end, from speaking also.

This is done by means of switches, which are of various forms.

(a.)—*The British Post Office System.*

119. In connection with this we must draw attention to the fact already stated (§ 91), that under this system metallic circuits are the rule, and single wires the exception. Under these circumstances there are three distinct ways in which a telephone can be placed intermediate.

(1.) It can be placed in one of the lines, as shown at *a* Fig. 125. The objection to this arrangement is that the inductive balance of the metallic loop is disturbed owing to the want of electrical symmetry between the two lines, and thus noises from induction are introduced.

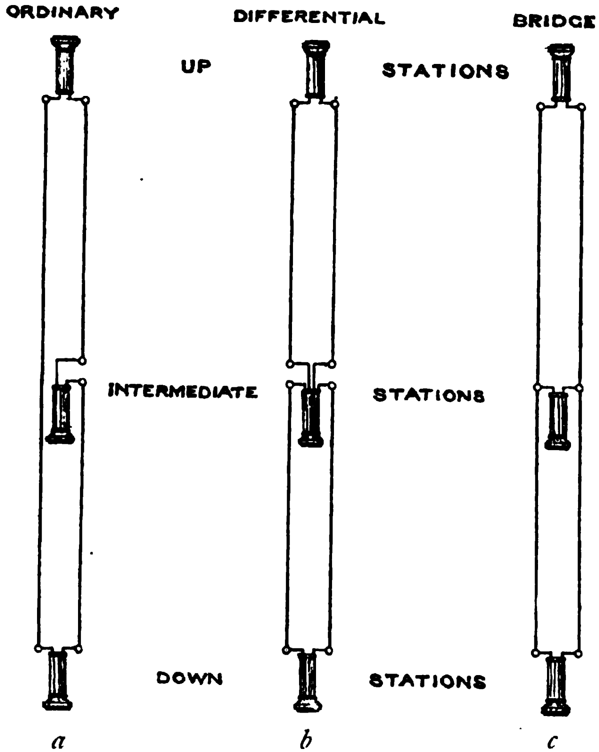


FIG. 125.

(2.) One part of the receiver coils and of the secondary section of the induction coil may be in one line, and a corresponding part in the other line. This plan is perfectly satisfactory telephonically, but, as it calls for double winding of the receivers and induction coils, certain electrical and mechanical objections are very liable to arise. The principle is shown at *b* in Fig. 125.

(3.) Each line is continuous through the intermediate station, and its instrument is joined across or "in bridge" as shown at *c* in Fig. 125. This arrangement is quite satisfactory from a telephonic point of view, even when six or eight telephones are placed in bridge (if the distance between each is not excessive). The electrical difficulties are very easily overcome by means of properly proportioned fixed resistance coils placed in the different sections of the circuit. The electro-magnetic inertia (§ 13) of the apparatus itself is here utilized. It operates the receiver; it chokes the circuit across the bridge, and so makes the working currents pass along the line.

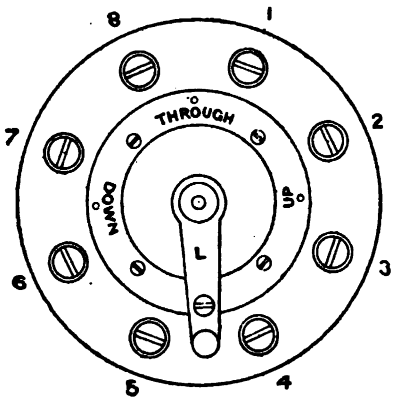


FIG. 126.

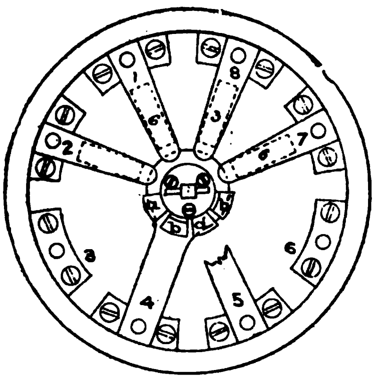


FIG. 127.

The Post Office system embraces each of these plans, and switches for each have therefore been designed;

but, as the general principle of the design of the switches, as well as the arrangement of the intermediate office, is not materially different with the several arrangements, we shall here describe only the last of the forms referred to.

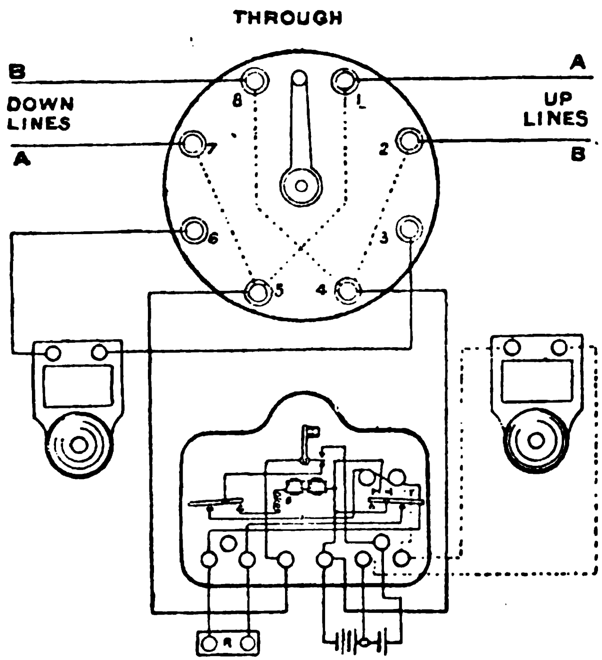


FIG. 128.

The front of the "Bridge Intermediate Switch" is shown by Fig. 126, and the back by Fig. 127.

1 and 2 are springs which are connected respectively to "up lines" A and B; 7 and 8 are similar springs joined to the corresponding "down lines." Beneath these springs are brass blocks, connected by brass straps alternately with terminals 3 and 6, as indicated by

3, 6, 3, 6. Terminals 3 and 6 are connected to the two terminals of an ordinary trembler bell. The movement of the switch lever L actuates a cam fixed upon the axis of the lever. This cam is in two sections, insulated from each other, and each having two alternating projections, *a*, *a'* being the projections on the upper section, and *b*, *b'* the projections on the lower section. The two sections are connected, by means of the springs shown, to terminals 5 and 4 respectively; which are joined to the two line terminals of the telephone. The lever and cam are in the position shown only in order that all the parts may be shown clearly. The actual

UP.

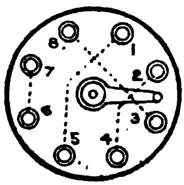


FIG. 129.

DOWN.

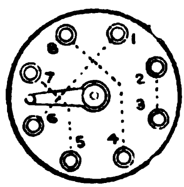


FIG. 130.

"positions" of the lever are at "Down," "Through," and "Up." When the lever is to "Through," all the cam projections are beneath the springs, lifting them clear of the brass blocks beneath; when the lever is turned to "Up," *a* and *b* are beneath 1 and 2 respectively, springs 7 and 8 falling to their position of rest upon their blocks 6 and 3. It may here be remarked that the four line springs are so constructed that they have a rubbing (cleaning) movement over the blocks beneath them.

Fig. 128 shows the complete electrical arrangement of apparatus at an intermediate switch station under this system—the dotted lines upon the switch itself showing the internal connections when the lever is in position "Through."

In this position lines A are continuous by way of terminals 1, 5, and 7, and lines B are continuous through 2, 4, and 8; the telephone, with its relay and trembler bell (to the right) being joined between A and B lines respectively at 5 and 4. The extra trembler bell shown at the left is, in this position, disconnected.

When the switch lever is turned to "Up" and "Down" the connections are changed to those shown in Figs. 129 and 130 respectively. In position "Down" the connections of the down lines remain to the telephone (5 and 4), but the up lines are now connected to the extra bell (6 and 3). The switch station can then be called by and speak to the down station, but can only be called by the up station through the extra bell. In the "Up" position these conditions are reversed, the up station can both call and be spoken to by the intermediate, while the down station can only call by means of the extra bell.

(*b.*)—*The German System.*

120. Fig. 131 gives the arrangement of an intermediate station as installed by the German Post Office, and employing Siemens' telephone (§ 30), (both transmitter and receiver).

The following description will give a clear idea of the construction of the switch.

To the upper and lower edge of plate G G (Fig. 132) are fastened, by means of screws, six flat springs, 1—6, of German silver, the plate itself being fixed to the inside of the front board of the telephone case. Inside the case, and in the free space enclosed by the six springs, is an axis, which protrudes through the front board of the case, and carries a flat handle outside (Fig. 131).

On the axis, close to the interior side of the front

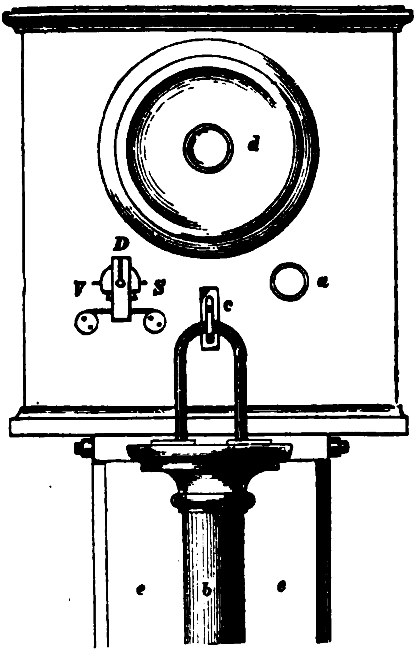


FIG. 131.

board, are fastened two insulated contact pieces, I and II, of brass, which lie in the same plane as the four springs, 3, 4, 5, and 6.

Another contact piece, III, provided with pointed ends, is fastened to the interior extremity of the axis, but insulated from it; it is likewise insulated from the contact pieces, I and II, and lies between the springs 1 and 2.

On turning the outside handle (the rotation on either side is limited to an angle of about 45° by a stop underneath the handle), the axis can assume three different positions with regard to the springs 1—6:—

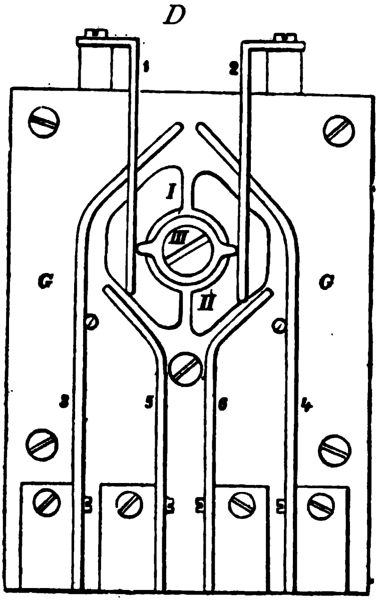


FIG. 132.

First Position.—Handle perpendicular, D. The centre contact piece presses against the springs 1 and 2; springs 3, 4, 5, and 6 are free (Fig. 132).

The line is through with the telephone intermediate.

Second Position.—Handle toward V. Contact piece I presses against springs 3 and 4; contact piece II presses against springs 5 and 6; springs 1 and 2 are free (Fig. 133).

The intermediate station can speak to the central station, the terminal station can call the intermediate station.

Third Position.—Handle towards S. Contact piece I

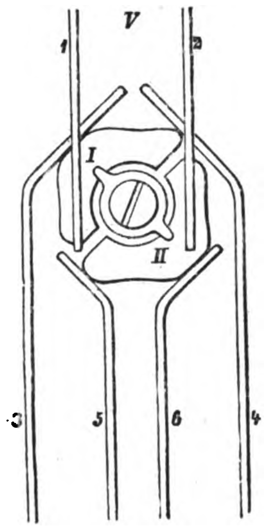


FIG. 133.

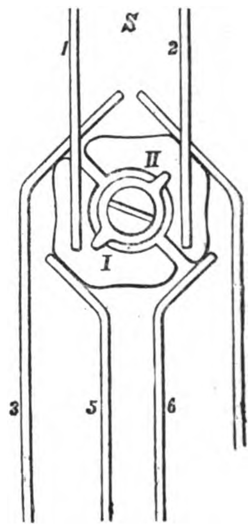


FIG. 134.

presses against springs 3 and 5; contact piece II against 4 and 6; springs 1 and 2 are free (Fig. 134).

The intermediate station can speak to the terminal station, the central station can call the intermediate station.

Two small pins are inserted in the front board of the telephone case; above and in connection with them lies a spring, which carries a flat piece of steel with a wedge-shaped tooth. The axle of the winch handle carries a disc with three triangular notches on its circumference. If the handle is in the position shown in Fig. 131—that is to say, if the intermediate station is through in either direction—the tooth of the spring gears into the centre notch. By turning the handle to the right the tooth is removed from the centre to the following notch, and the intermediate is in communication with the terminal station (third position); while

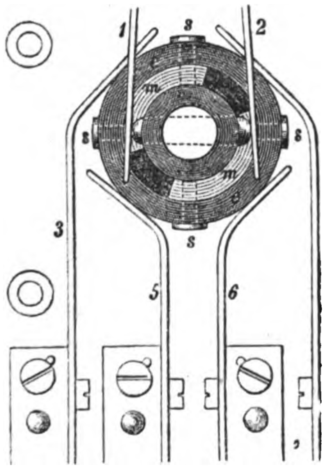


FIG. 135.

a turn to the left puts the operator at the intermediate station through to the central station, and enables the terminal station to call the intermediate station. The notches are constructed in such a way that the handle cannot be turned either to the right or the left beyond the position taken up when the tooth gears in either with the right or the left hand notch.

121. In a later and somewhat modified form, the two

contact pieces I and II consist of two curved brass strips *m*, which are surrounded by an ebonite ring *e* (Fig. 135), to which they are fixed by the four studs *s*. By the

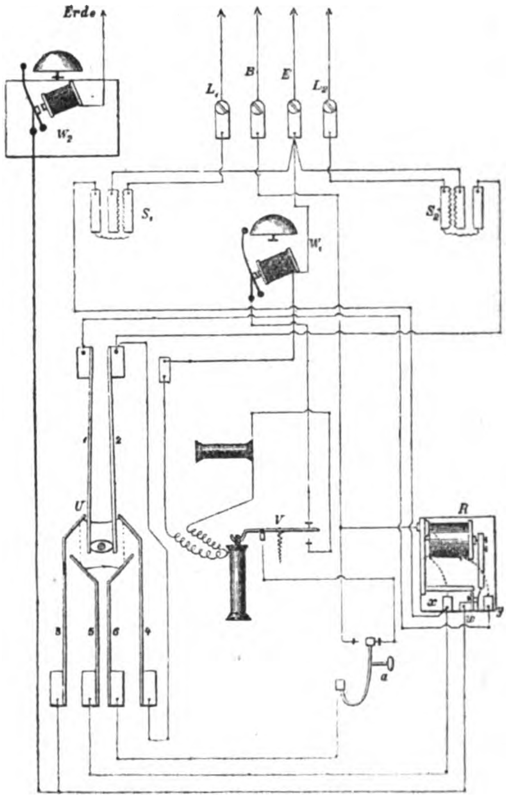


Fig 136.

turning of the handle to the right or left the springs 3, 4, 5, 6 are connected together in pairs through the studs *s* and the brass pieces *m*, whilst in the vertical position of the handle a pin with rounded extremities connects the two springs 1 and 2, and the other springs are insulated.

The current path for the different connections of the intermediate station is shown in Fig. 136.

First Position.—The current arriving from the central station through L_1 passes through the lightning protector S_1, the electro-magnet of the relay R, and thence through springs 1 and 2, the lightning protector S_2, and terminal L_2 to the circuit of the terminal station.

The terminal and central stations can communicate.

If in this position the battery contact is closed by the terminal or the central station, the relay R is actuated, closing the local circuit, and so causing the bell W_3 to ring. By a pre-arranged system of signals the intermediate station can tell which office is being called.

Second Position.—The connections are marked in the figure by firm curved lines between the springs; the springs 1 and 2 are free.

A current arriving from the central station passes through L_1, S_1, thence through springs 5 and 6, press-button *a*, switch-lever V, call bell W_1, and, finally, to earth.

The intermediate is called, and can, after unhooking the telephone, speak to the central station.

A current arriving from the terminal station through L_2 passes through S_2, springs 4 and 3, call bell W_2, and finally to earth.

The intermediate station, therefore, receives the call from the terminal station.

Third Position.—The connections are shown in the figure by dotted lines. Springs 1 and 2 are free.

A current arriving from the terminal station passes through L_2, S_2, springs 4 and 6, through the press-button *a*, thence to switch-lever V, and, through call bell W_1, to earth.

After unhooking the telephone, the intermediate station can speak to the terminal station.

A current arriving from the central station through L, passes through S_1, thence through springs 5 and 3, and call bell W_2, to earth.

The intermediate station thus receives the call of the central station.

It will be noticed that in this system the relay is not used except when the two lines are through.

(*c.*)—*Lassance Switch for Intermediate Stations. (Belgian System.**)

122. In the apparatus represented in Figs. 137 and 138, D is a wooden handle which is pivoted upon an insulating board E, and whose thinned extremities are provided with copper plates *d*, which act as springs. These plates are intended to join, on the one hand, the contacts *a b*, *a c*, *c b*, which are in connection with the two lines and the telephone M of the station; and, on the other hand, the contacts *a s* and *c s*, which correspond with the lines, and with an additional call bell S. In order to prevent the longer branch of the handle from touching the inner contacts, it is bent upwards, and can thus move freely over them.

It will be seen from Fig. 137 that when, for instance the contacts *a* and *b* are made—that is to say, when station A is on the telephone—the contacts *c* and *s* are made at the same time, and station C is on the call bell.

* La Lumière Electrique, No. 13, 1885.

It will also be seen that, when stations A and C are joined directly, the intermediate station is completely out of circuit, and cannot hear the conversation.

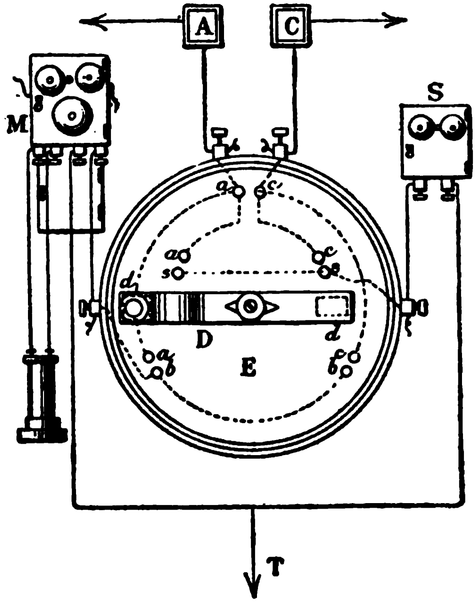


FIG. 137.

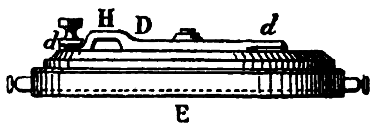


FIG. 138.

As soon, however, as the conversation is finished, the intermediate station can be informed of the fact by the play of the indicators A and C.

Finally, the position of the handle in the figure corresponds to the insulation of the two lines.

(*d.*) *Hartmann & Braun's System.*

123. This simple arrangement, introduced by Messrs. Hartmann & Braun, of Bockenheim, near Frankfort-on-Maine, is represented in Fig. 139. *a b* and *c* are three metallic blocks fixed on a small board; to these blocks are soldered four metallic spring plates, *l*, *l'*, *l''*, and *l'''*. The two former, being stronger than the latter, remove them from the metal studs *g* and *g'* by means of the insulating studs *i* and *i'*, and thus place themselves in contact with those studs. The latter are, as indicated by the dotted line, in electric communication with the call bell S. L' and L'' are the terminals of the two lines, T is earth, and A leads to the telephonic apparatus of the intermediate station. H is a two-armed lever, whose shorter arm carries two contact rods which can act on the springs *l* and *l'*. On moving the lever H to the left, spring *l'* is pushed to the right, leaves the stud *g'*, and allows spring *l''* to enter into contact with *g'*. Analogous changes are effected by moving lever H to the right. The blocks *a c* are provided with the pointed screws *v* and *v'*, which, approaching block *b* within a fraction of a millimetre, can act as a lightning

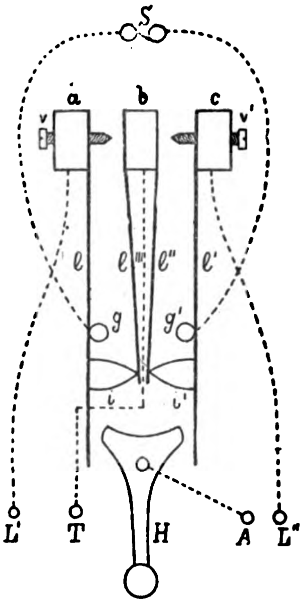


FIG. 139.

protector. In the position of the lever H, represented in the figure, the telephone of the intermediate station is disconnected; the two end stations are in direct communication, and call bell S alone is in circuit to give the signal for the end of the conversation. When the lever is moved to the right, line L′ is, through *a*, *l*, H, in communication with the apparatus of the intermediate station; whilst line L″ goes through *l*′, *g*′, S, *g*, *l*″, and to earth. When the lever H is moved to the left, line L″ is in communication with the apparatus, and L′ goes to earth through call bell S.

CHAPTER XIV.

TELEPHONE EXCHANGES.

THE ENGLISH POST OFFICE SYSTEM.

124. *The Switchboard.*— The switchboard is an apparatus which enables each subscriber of the telephonic network to call the exchange and to enter into communication with it, and which further enables the operator at the exchange to effect the connection of any two subscribers in the shortest and safest manner. For the first-named purpose the switchboard

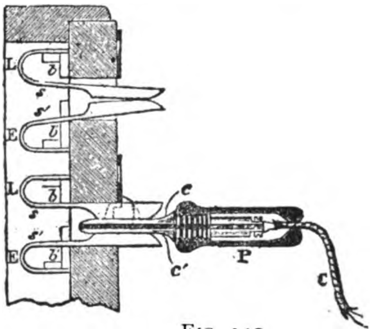


FIG. 140.

must have for each line a seperate electro-magnet, which is actuated by a current sent into line from the subscriber's terminal station, and produces an easily visible, and also audible, signal.

The form of switchboard adopted by the English Post Office for ordinary exchanges is shown by Fig. 140, which is drawn one-third of the actual size.

Each hole of the switch comprises two brass springs, *s s'*, fixed behind a mahogany frame, through which the thick ends of the springs project. These springs have a tendency to close together, and so, in their normal condition, they are in good electrical contact. The several holes are placed in electrical communication with each other by means of flexible cords, C, to each end of which is attached a plug, P. The flexible cord contains two insulated wires, which are connected to the two brass faces, *c c'*, of the plug, and when the plug is inserted into a switch-hole, the two springs, *s s'*, are separated, and brought into connection respectively with the faces, *c c'*, of the plug. Upon the upper face, *c*, of the plug is rivetted a brass projecting piece, which slides into a slot in the upper spring when the plug is inserted in a hole. This projecting piece is so placed upon the plug that if the latter is inserted between the springs upside down they will not hold it, but will force it out again, thus effectually securing that the plug shall be properly inserted. A horn thimble, which screws on to the body of the plug, serves at once as a protector for the connection between cord and plug, and as a handle for the plug.

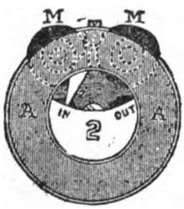


FIG. 141.

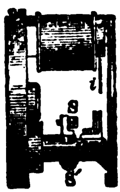


FIG. 142.

125. *The Indicator.*—Each subscriber's line at the exchange is connected to an indicator, which is required to give a means of indicating whether the line is disengaged or not, and also to act as a means by which the

subscriber can gain attention from the exchange. The method employed to effect this forms a special feature of this system. The indicator is shown in front and side elevation in Figs. 141 and 142. Upon a disc of brass which forms the base of each indicator is mounted an electro-magnet, M M, having as an armature a ring of soft iron, A A, which is so hinged to a small pillar at *a* that it has a tendency to fall away from M M, and will do so unless there is a current passing through the coils. The ring carries a small plate, which is engraved with the number or name of the subscriber. Pivotted upon a small bridge between the coils, and free to move between the poles, is a small magnetic needle, *i*, which deflects to right or left, according to the direction of the current in the coil, or hangs vertical if no current is flowing, and serves as an index as to whether the line is disengaged or not. Upon the pillar which carries the shutter is an insulated stud, S S′, against which the ring rests when it is not held up by the electro-magnet; if, therefore, a bell and battery are connected up in circuit with the stud S and the base of the indicator, the bell will ring so long as the shutter is down, and this method of calling attention can therefore be adopted if desired.

126. *Ordinary Telephone Exchange Working.*—The ordinary method of connecting the renters' lines with the exchange is shown in Fig. 143.

It will be seen that the "A" line of each renter is connected through the indicator to the upper spring of the switch-hole, and that the corresponding "B" line is connected direct to the lower spring. In the few cases under the Post Office system in which no "B" or return wire is used, the lower springs are connected direct to earth.

On referring to the figure, the different conditions of intercommunication will be easily understood. Subscriber No. 1 is shown to be in communication with the exchange itself. There is no current on the line, as is shown by the fact that the magnetic needle of the indicator is vertical. A peg is inserted between the springs of switch-hole No. 1, the two sides of which are connected (by means of a flexible cord shown in the figure as two parallel lines) to a telephone at the exchange. The course of the undulatory speaking currents will therefore be from No. 1

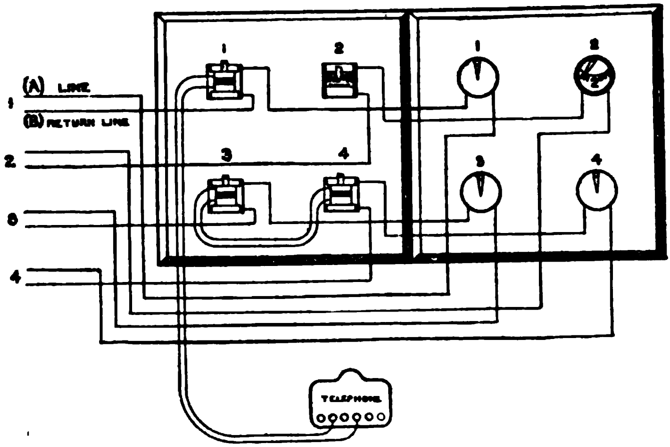


FIG. 143.

line "A," through No. 1 indicator, to the upper spring of the switch-hole, through the exchange telephone, and back to No. 1 line "B" by way of the lower spring.

No. 2 subscriber is shown as disengaged: the switch springs are closed together, the indicator shutter is up, and the magnetic needle is deflected. The permanent current indicated by the deflected needle will be explained directly.

Again, subscribers Nos. 3 and 4 are shown as communicating with each other; the undulatory speaking currents passing through the springs of both switch-holes and through both indicators.

We will now briefly describe the means by which these different conditions of intercommunication are arranged for.

It will have been noticed in the description of the indicator (§ 125) that the only means of keeping up the shutter is by a current flowing through the coils. As stated in that description, this forms a special feature of the Post Office system. Each subscriber in connection with the exchange is provided with a Daniell battery, which is so connected with the telephone that, so long as the switch levers of the telephone are depressed—that is, so long as the tubes are in their rests—a current from the Daniell battery will flow to the exchange lines; this current, flowing through the indicator at the exchange, enables the electro-magnet to hold the shutter or ring A in a vertical position, and to deflect the magnetic needle. If, now, the subscriber desires to communicate with the exchange, he has only to take the tubes from their position of rest. This disconnects the "permanent current" from the line, and the shutter at the exchange drops, thus attracting the attention of the exchange clerk, who thereupon puts a plug attached to one of the exchange telephones into the subscriber's switch-hole (No. 1, Fig. 143), and ascertains what is required. If the subscriber desires to speak to another subscriber (say No. 3 wants No. 4), the exchange clerk calls up the required subscriber, says, "Through to No. 3," and puts in the through plugs as shown at 3 and 4 in the figure. The calling from the exchange is effected by means of a calling battery, of sufficient electromotive force to send a current of 40 milli-ampères through the longest line on the exchange system. The "permanent current" passes through the coils of a relay at the subscriber's office, and this relay, which is for actuating the subscriber's call-bell, is "biased" against the permanent current (about 20 milliampères); but when the permanent current is strengthened by the calling current acting in the same direction, the bias of the relay is overcome, and the call is effected.

As the permanent currents from all lines flow in the same direction, if two communicating lines were joined straight through, "A" line to "A" line and "B" line to "B" line, the two currents would neutralise each other. In order that this may not be so the switch-plug cords are crossed, that wire in the cord which goes to the upper side of one plug being connected to the lower side of the other plug. This is shown in the figure (Nos. 3 and 4). By this means, when, at the end of a communication, the two corresponding subscribers replace their hearing tubes, the currents on either side of the exchange combine, and so, by deflecting the magnetic needles of the two indicators at the exchange, give notice to the exchange clerk that the conversation is at an end. The plugs are then removed, and the lines left in their normal condition.

127. Beyond the primary advantages of the permanent current system, such as the automatic indication at the exchange of the conclusion of a conversation between two subscribers, an incidental advantage also arises in the fact that the permanent current acts as a test for the line, and at once indicates when a disconnection, a contact, or any other fault comes on. Further, it shows when a subscriber omits to replace the tubes in the switch levers, and so prevents waste of time in calling.

In order to gain the attention of any subscriber who has inadvertently left off the tubes, a "buzzer," or "howler," is placed in the circuit of the calling battery at the exchange. It is an induction coil sending rapid intermittent currents to the subscriber's line, which, acting upon his telephone receiver, make a loud buzzing sound and so attract attention.

128. The arrangement of the different apparatus at an exchange has an important bearing upon the expedition

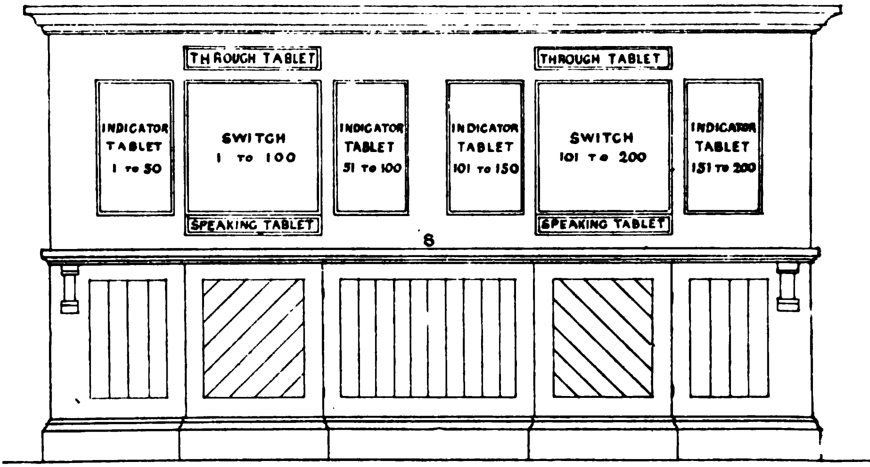


FIG. 144.

and efficiency of its working; unless the operators are able to see at a glance the condition of every subscriber's line and can easily control their several sections, great confusion and much loss of time are sure to arise. The general arrangement of a medium-sized exchange (of from 100 to 300 subscribers) under this administration is shown by Fig. 144.

Each switchboard of one hundred holes is placed in charge of two clerks, and the corresponding indicators are fixed upon tablets in two groups, one on each side of the switchboard.

Each switch-clerk is provided with a telephone by which to communicate with subscribers, and there are other telephones which are used for sending and receiving telegraphic messages. These telephones are joined up to a "speaking tablet" fixed beneath each switchboard, with two connection-screws for each instrument. To these two screws a flexible cord is attached; this is taken down through the shelf, S, of the switch-frame, round a light pulley, back through the shelf, and then connected to a switch-plug. Each of these speaking telephones can thus be placed in communication with any one of the subscribers on the switchboard, and when not in use the cords of the speaking plugs are drawn beneath the shelf by the pulleys, and so kept clear of the switch.

Where more than one hundred subscribers are connected to an exchange, provision is made for the communication of subscribers fixed on different switchboards by means of "through tablets" fixed above the switchboard. These consist of switch-holes similar to those of an ordinary switchboard, connected in sets: that is, (say) A, B, C of No. I switch are connected respectively to A, B, C of No. II switch; D, E, F of No. I to D, E, F of No. III; and G, H, I of No. II to G, H, I of No. III. Thus, if subscriber 58 wishes to speak to subscriber 223 the switch-clerk of No. I places a pair of plugs in holes 58 and (say) E, and instructs the switch-clerk of No. III to similarly connect E and 223.

129. *Special Switchboards.*—It is found that on lines of any considerable length the disturbing influence caused by the self-induction of the indicators seriously

impairs the efficiency of the circuit, and the plan of working with the indicators in "bridge" (§119) has therefore been resorted to at several exchanges. The two indicators are by this means got out of the direct line altogether and placed across as shown in Fig. 145. The indicator for this system is similar to that already described, except that the electro-magnet is lengthened and wound to a high resistance (1,000 ohms). The coils also have an iron casing surrounding each, to increase their electro-magnetic inertia. The indicator is connected between the springs of the switch-hole, which for this reason are kept apart, as shown in Fig. 146, by means of small ebonite stop-pieces (not shown), and so serve merely to connect the lines of the different circuits when the plugs are inserted.

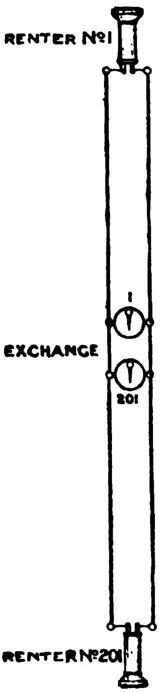


FIG. 145.

A "multiple" switchboard on the bridge system, and of a special character, has also been devised, but, as the principle will be dealt with in connection with other administrations, it is not necessary to describe it in this place.

130. *Intermediate Offices.*—The special requirements introduced by the existence of an intermediate office upon a circuit have been met in the following manner:

A special intermediate switch for exchange circuits has been devised. The principle of its construction is the same as that shown in Figs. 126 and 127, and need not therefore be described; its essential difference is that it has only two positions, "down" and "exchange," of which the latter is the normal position. At the intermediate office, besides the switch and telephone, there

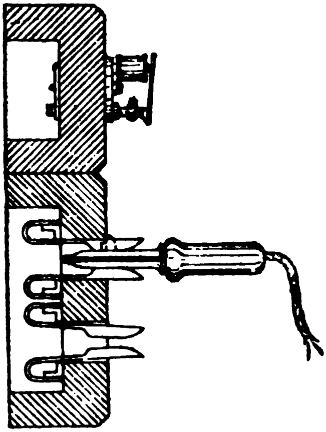


FIG. 146.

are a polarised relay, with a magnetic needle similar to that attached to the indicators (§ 125); a non-polarised relay, and one trembler bell which is actuated by either relay.

The connections are shown by Fig. 147, from which the local connections of the relays and the microphone circuit of the telephone are omitted for the sake of clearness, and which gives the connections in position "Exchange."

In the normal position the two relays, joined in series, are in "bridge" across the two lines, and a permanent current flows to the exchange from the down office. In this position both offices gain the attention of the exchange by repeated depressions of the press-button on the telephone. In the case of the down office, this breaks and restores the permanent current, and so the magnetic needle of the indicator at the exchange moves repeatedly from left to vertical; but in the case of the intermediate

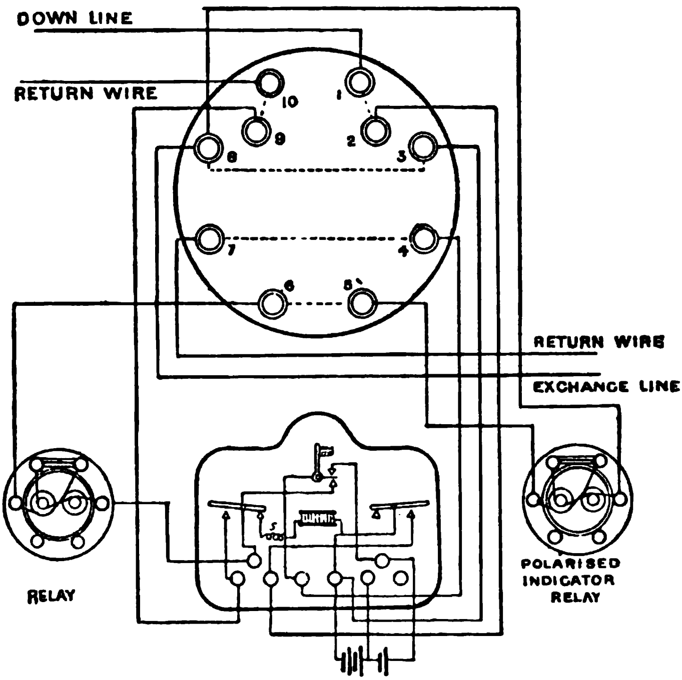


FIG. 147.

office the repeated depression *reverses* and restores the permanent current, and the needle consequently vibrates from side to side. The exchange clerk therefore easily knows which office is calling. For calling the intermediate, the speaking-telephone plug is inserted reversed (a reversible plug being provided for this purpose), and one ring given; while for calling the down office the plug is inserted in the usual way; and as the relays at both offices are polarised, the arrangement is such that only the office required is called. The down office is provided with a separate press-button for calling the intermediate, which is arranged to augment the permanent current without breaking, so actuating the relay at the intermediate station without disturbing the exchange. Two rings are given by the down office in calling the intermediate station, while only one is given by the exchange. In order to call the down office or to answer its call, the intermediate switch must first be turned to "down," and then the button be depressed in the usual way. Turning the switch to "down" breaks the permanent current from the exchange, and so drops the indicator shutter; but this does not affect the working, as the indicator needle hangs vertical, and it is understood that when at either office, or at the exchange, the indicator needle is vertical, it is a sign that the line is engaged, and so all conditions of working on an intermediate circuit are as straightforward and simple as on an ordinary circuit. The internal connections of the switch at position "down" are shown in Fig. 148.

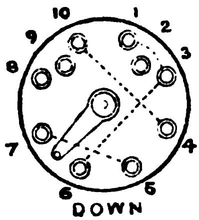


FIG. 148.

131. *Trunk Wires.*—When there are telephone exchanges at neighbouring towns, it is often advantageous to connect the exchanges, so as to permit the subscribers of one exchange to communicate with those of the other. This is effected by means of "trunk" wires between the

different exchanges. In this way, for instance, the exchanges at Newcastle-on-Tyne, South Shields, Sunderland, the Hartlepools, Stockton, and Middlesborough are connected by trunk wires, and the subscribers at any of those towns can therefore communicate with those connected with any of the other exchanges. The number of trunk wires is, of course, limited, so that it is necessary to limit the time of their use for each communication. Three minutes is the time allowed, and if other subscribers are waiting to go through at the end of that time, the wires are disconnected, and the subscribers informed of the fact. If, however, the line is not required, the conversation is not interrupted.

132. There are a few points as regards management which may be mentioned.

The experience of nearly every exchange is that it is more advisable to depend upon numbers than upon names in indicating and calling subscribers. Mistakes in numbers are not so frequently made, and can be provided against, and, when they occur, are more easily rectified ; numbers, moreover, are shorter.

Switching is greatly facilitated if subscribers who frequently inter-communicate are placed as near together as possible. The indicators of two or more lines used by the same subscribers should be side by side.

Where telegraphic or other messages are delivered or received by telephone, the whole message should invariably be repeated back to the sending station.

Numbers and names should be *spelt*, as well as spoken thus :—" T w e n t y—twenty, f o u r—four : twenty-four."

Even spelling is not always sufficient, difficulty being experienced in the confusion of certain letters—b and p ; t and d ; m and n, for instance, being mistaken one for the other. This is surmounted by giving words for doubtful letters, thus :—" p for Paris" ; " t for Thomas" ; " n for Newcastle" ; etc.

It will be noticed that the number-plate on the indicator is also marked "IN," and "OUT," and that the magnetic needle ordinarily points to "IN." Some subscribers are provided with a switch, by which they can reverse the direction of the permanent current, and so cause the needle of their indicator at the exchange to point to "IN" or "OUT" at will. It is found, however, that these switches are very liable to be left at "OUT," and so mislead the exchange clerks. Their use, therefore, is not much encouraged.

Ordinarily attendance is given at the telephone exchange so long as the telegraph office to which it is attached is open, but after ordinary business hours the calls are generally so infrequent that the attendants are withdrawn. Provision is therefore made for the subscribers to gain attention by means of the local circuit of the indicator. This is joined up in circuit with a battery and a trembler bell fixed in the instrument-room ; and when the shutter of any indicator falls, the "night-bell" circuit is closed through the insulated contact S′ (Fig. 142), and the bell rings until attention is given. This night-bell circuit is, of course, disconnected so long as the switch-clerks are in attendance.

It is found that the average time occupied by subscribers for each communication is about three minutes ; and it has not been found necessary or desirable to make any restriction as to time, although, if the wires are occupied for a very lengthened period, the exchange clerk is permitted politely to draw attention to the fact.

Regular and prompt attention to *every call* should be a special feature of every telephone exchange, and under the Post Office system this is strictly insisted upon. No switch-clerk is permitted to have charge of more than fifty renters, and attention to their inter-communication requirements is the sole duty of such clerk, other special clerks being appointed for the transmitting and receiving of messages. At large exchanges each clerk has to attend to not more than forty subscribers.

Every effort is made to prevent the introduction of disturbing noises in the exchange office, which would tend to make communication between the clerks and the subscribers more difficult and less reliable. To effect this object the floors should be carpeted, and ordinary conversation not permitted.

The testing of the switch-cords is a matter that must not be overlooked. Each cord should be tested once or twice a day at least. With the permanent current system this is very readily done by simply "putting through" two disengaged lines. If the cord is not faulty, the indicator needles will remain deflected as usual; whereas if the cord is disconnected at any point, the needles will become vertical. If now one plug be reversed the currents from the two lines being opposed should neutralise each other. If they do not, it indicates that there is some fault in the loop. If the system were open circuit a galvanometer with two spare switch-holes and a battery would be provided for cord testing.

In order to facilitate the accurate taking off of messages, the message-clerks sit in small cabinets of special construction, which are practically sound proof. After a series of experiments the Post Office Department managed to obtain the required result by the following arrangement :—

The ordinary cabinet is about three feet square, and eight feet high, with a pyramidal roof. It is constructed as a frame-work with as little wood as possible consistent with strength, with a door, and suitable provision for fixing a bracket seat and the telephone. The frame thus constructed is filled in in the following way: First, every space is filled with 5 lb. laminated lead, fixed about one-third of the thickness of the frame (which is two inches) inwards. On the outside of this is placed one layer, and on the inside two layers, of doe-hair felt. The whole is then covered inside and out with Hessian canvas, and, finally, finished with a covering of leather-cloth. Within this comparatively light structure even loud external noises are scarcely audible.

At most telephone exchanges a silence cabinet is provided in the public office, which subscribers are permitted to use for communication with their own offices, or with other subscribers.

CHAPTER XV.

TELEPHONE EXCHANGES.

THE GERMAN SYSTEM.

133. THE working of central stations differs according to country and locality, but as regards essential features differs only according to whether one or the other of the two leading principles is adopted.

According to one method, the subscriber who wishes to enter into conversation with another subscriber first calls the central station; upon receiving an answer from the latter, the caller informs the operator at the exchange of the number of the desired correspondent, who is, in his turn, called by the operator. As soon as an answer has been received to the latter call, connection is made between the two branch lines.

According to the second method, the calling subscriber likewise designates the desired correspondent, and, if the latter is disengaged, connection is forthwith made at the exchange between the two branch lines, and both the call and further communication are left to the calling subscriber.

In both cases the caller has to inform the central station of the end of the conversation by means of some prescribed form of clearing-out signal.

As soon as this has been done, the branch lines are again disconnected, and return to their normal condition.

The former method was generally used at the earliest exchanges, and is still to be found in many central stations; it presents the advantage that at the exchange the same signal can be used both for the call and for the end of the conversation, without fear of mistaking either of the signals. On the other hand, this system requires a larger staff of *employés*, and the working expenses are proportionately higher. The advantages and drawbacks of the second method of working will be clearly discernible from these remarks and the choice between the two will depend upon the consideration whether safety of working or economy has paramount claims.

The earliest telephone exchanges had, besides the apparatus which announced the fact of a subscriber having called, and of which each branch line possessed one, a number of special "clearing-out relays," or apparatus for announcing the end of a conversation. The number of these apparatus may be limited where telephonic messages are not very numerous; but, on the other hand, where a lively telephonic inter-communication takes place, the number is considerably increased. It is, therefore, of great importance to devise a means for obtaining security in distinguishing the calling and clearing-out signal, employing one and the same apparatus for both purposes, and this has been effected in the German central stations in the following way:—

Two very flexible springs f_1 and f_2 (Fig. 149) are connected to the lever H of the subscriber's instrument, which serves for the suspension of the telephone; the springs are insulated both from the lever and from each other. One of these springs is connected to earth, the other to the contact *a* of press-button T. When the telephone is suspended—that is to say, when the apparatus is at rest—spring f_2 presses against contact screw n_2, and spring f_1 against screw p_2; on unhooking the telephone the springs f_1 and f_2 go against n_1 and p_1 respectively. Now, as the screws p_1 and p_2 are in connection with the

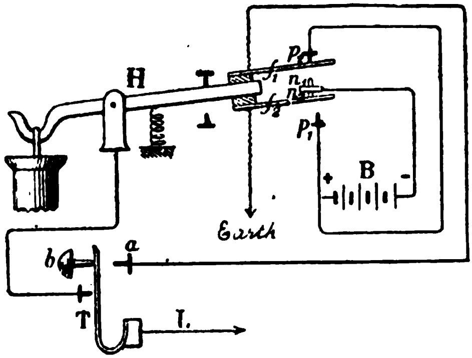


FIG. 149.

positive pole of the call battery B, and n_1 and n_2, on the other hand, with the negative pole of this battery, a positive current is sent into the line by pressing key T, provided the telephone be suspended ; while a negative current passes if the telephone is unhooked. The signalling apparatus at the central station is so arranged that it is actuated only by a positive current from the corresponding station.

The following is, then, the course of telephonic correspondence :—

The subscriber presses the stud of the press button T; a positive current passes through the line to central station, and there rings the call bell. The subscriber then unhooks his telephone to give his instructions to the exchange. On receiving answer from the latter that the desired communication has been established, he again presses the stud of the key to call his correspondent, keeping his telephone in his hand all the time. A negative current is thus sent into line and rings the call bell of the required subscriber, without, however, actuating the polarised signalling apparatus at the exchange. As soon as the conversation is finished, the telephone is again suspended to the hook, and the press button is then depressed for the purpose of giving the clearing-out signal. A positive current now passes into line, actuates the apparatus at the central station, and thus informs the operator in an unmistakable manner of the end of the conversation.

It often happens that the subscriber, being in a hurry, forgets the clearing-out signal. In order to avoid any disturbance which might arise from such neglect, the lever H is provided with a contrivance by means of which, on suspending the telephone, the clearing-out signal is given automatically. This is done by fastening on to lever H a nose N (Fig. 150), which is movable in such a way that, on unhooking the telephone, it freely passes an insulated button *i* fixed to the free extremity of spring *g*. On suspending the telephone the nose N, moving upwards with the lever, presses the spring *g*, which is in connection with the line, against the contact screw *h*, which is connected to the positive pole of the battery. In order to keep the negative pole of the battery to earth during the upward movement of the nose

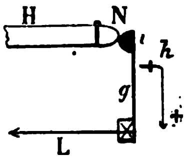


FIG. 150.

N, and the corresponding movement of the springs f_1 and f_2, an arrangement indicated in Fig. 151 may be adopted. A second spring g_1, connected to earth, and similar to g, is pressed by the nose N against a contact screw h_1, which

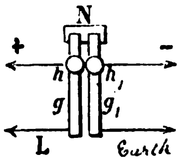


FIG. 151.

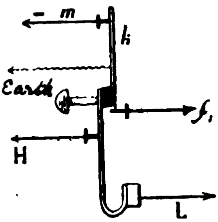


FIG. 152.

is in connection with the negative pole of the battery. Or else a spring k, connected to earth (Fig. 152), is joined to the key in such a way that, on pressing the key, the connection between the spring and the contact screw m is broken. This latter screw is connected to the negative pole of the battery.

The automatic arrangement just described permits of a very considerable simplification of the working system by the introduction of a modification of the original plan; namely, the employment of currents in the same direction for calling both the central station and the subscriber's correspondent, and the use of a current in the opposite direction for a clearing-out signal. Fig. 153 shows the modified connections. In its normal position the insulated spring k, which is permanently connected to earth, presses against a contact p, which is in connection with the positive pole, whilst on depressing the key it goes against a contact screw n, connected to the negative pole. The lever H for the suspension of the telephone is provided with a nose, which, on suspending the telephone, presses the spring *g* against the contact screw *h*. This brings the line L, by means of spring *g*, and the axle bearings of lever H, in connection with the negative pole of battery B. As will be seen from the sketch, a positive current is sent into line by the pressing of the key, whatever the position of the lever H; by the suspension, however, of the telephone, the spring *g* is pressed against the screw *h*, and a negative current is sent into line.

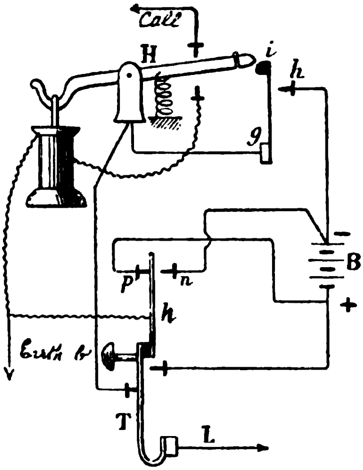


FIG. 153.

The former current causes the falling of the annunciator-drop at the central station, or, what is even preferable, causes the appearance of a disc exhibiting the number of the calling subscriber; the latter current brings back the disc to its original position.

The reason why the disc signal is preferable to the annunciator-drop is that the former can be worked with a weaker current.

134. Having now shown how nearly absolute security in the transmission and reception of signals is obtained, we proceed to the description of the characteristic features of a central station as worked by the German Post Office at Berlin.

The line wires are led to a wooden tower (Fig. 154) which is erected on the roof of the central station, and the posts carrying the wires are grouped around

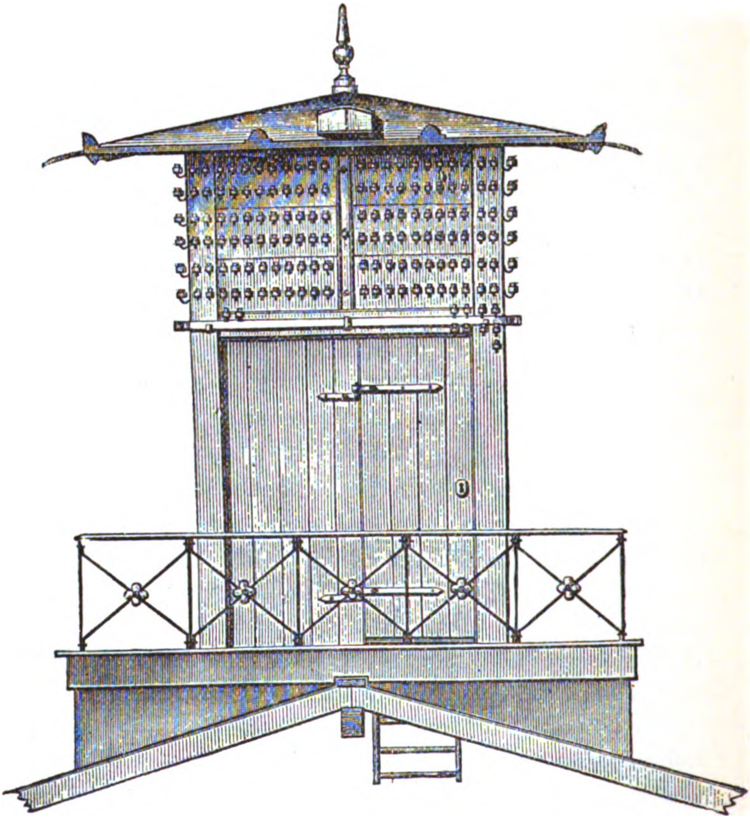


FIG. 154.

it in the form of a square or of an octagon. The tower measures in the ground plan 2·20 square metres, and rises about 4 metres above the platform. The roof contains two skylights, and there is a door in one of the

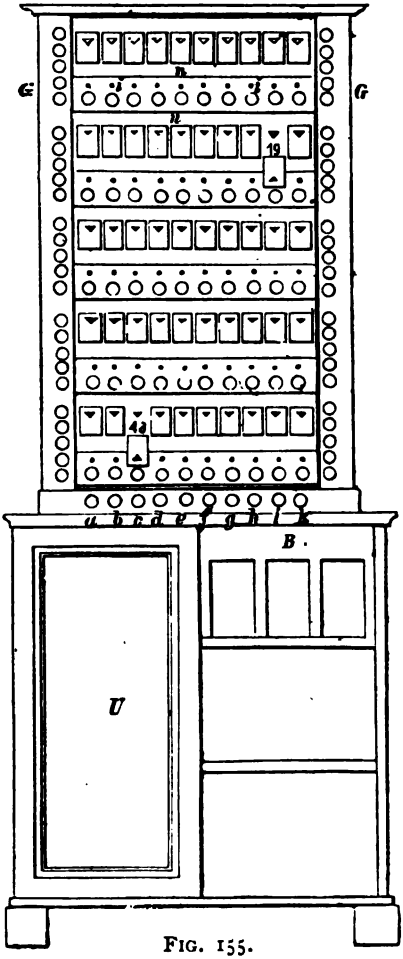


FIG. 155.

side walls. The upper part of the tower is provided on all four sides with small insulators, for from 500 to 600 line wires. The bare wire ends at the insulators, and four-wire lead-covered cables lead from them to the switchboards.

135. A front view of the German switchboard for fifty subscribers is given in Fig. 155. It contains fifty switch-holes, with annunciators of the construction shown in Fig. 156, arranged in five horizontal rows of ten each.

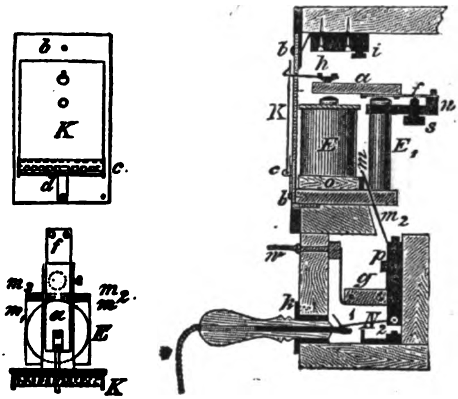


FIG. 156.

The annunciator, of which Fig. 156 gives front view, plan and section, consists of an electro-magnet E (3,500 windings, 150 ohms), with an armature *a*, which holds up a drop K, movable about *c*, and releases it on a call being made. The drop, which falls down, assisted by a small flat spring *d*, then rests against the brass pin *w*, and thereby closes the local circuit of a call bell.

The switch arrangement for making connection shown at N in the section, consists of two angular shaped brass pieces, of which the lower one, 2, is fastened to the woodwork of the switchboard, whilst the upper piece, 1, is movable about a hinge, and connected with the brass plate *p*. A spiral spring fastened to the hinge presses 1 against 2, which is in connection with earth. Immediately in front of the switch-springs is an orifice *k*, lined with brass for the reception of a plug. In the normal position a current sent from the subscriber's line passes through m_3, and m_1, then through the electro-magnet E to m, m_1', p, 1 and 2, and, thence to earth; the armature *a* is attracted, and the little hook *h* releases the drop.

136. For making the connections a flexible cord, consisting of a number of thin copper wires, wound with wool or silk, is used. In order to join two subscribers' lines the cord has a plug at each end; if the cord has only to join some branch line or other to a telephonic apparatus, one end of it receives, instead of the plug, a simple copper wire. The plug (Fig. 157) can be inserted into the collar *k* of the switch-hole as far as the shoulder *b*. The brass pin *a*, 4 mm. thick, and sharpened at its extremity, is in metallic connection with the flexible cord, and also, by means of a screw, with a brass ring surrounding the handle at *b*. The pin *a* of the inserted plug lifts the upper part 1 of the switch-spring N, and separates it from earth, and itself remains in connection with 1, so connecting 1 to the speaking apparatus, or to a second annunciator, by means of the flexible cord.

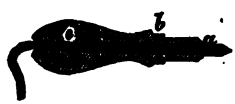


FIG. 157.

137. If the number of subscribers of an exchange is not very large—does not, for instance, exceed one hundred—

connection can be made between any two subscribers without any difficulty. The two switchboards, each for fifty subscribers, can be placed in such a manner that even the two most distant switch-springs can be connected by a flexible cord.

If the number of subscribers reaches two hundred, the connections can be made in the same simple manner if, in addition to the four switchboards containing the necessary number of indicators and switch-holes, supplementary switches are employed. The arrangement of such an exchange installed at Berlin by the German Post Office is represented in Fig. 158. The

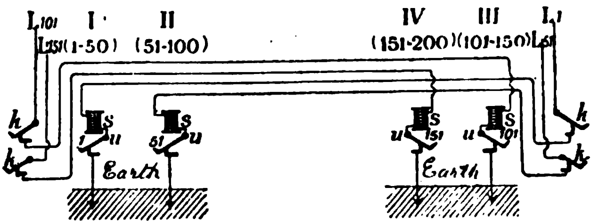


FIG. 158.

four switchboards, arranged for fifty subscribers each, are placed in two groups of two in such a manner that a direct connection of the branch lines belonging to each group of switchboards can easily be effected by means of flexible cords.

Alongside of the switchboards I. and II., which contain the indicators S, together with the switch-springs *u* for the connection of Nos. 1—50 and Nos. 51—100, special commutators (*k*) of fifty switch-holes each are placed. Similar supplementary switches are placed close to the other group of switchboards III. and IV.

It will be seen from the sketch that the branch wires belonging to one group of switchboards in the first place go to the switches *k* of the second group, and thence through their own switches to the electro-magnets of the indicators. With such an arrangement, the connection of any two branch lines can easily be effected. The operator has, before making connection, only to make sure that the called line belonging to another group to which he does not attend, is not occupied already; and this he can ascertain without loss of time, provided the switchboards are conveniently placed.

138. It is a different matter, however, if the number of subscribers exceed two hundred. In that case, the operator, who has to ascertain whether the called line belonging to another operator's group is free, has to shout across the room, and, besides, has to leave his place in order to make the desired connection. Now, while he is away from his place another call may occur, and his place must, therefore, during his temporary absence, be occupied by some one else. The drawbacks of this system are, therefore, an unavoidable confusion and noise, which must necessarily interfere with successful and efficient working, and further increased expense caused by a rather numerous staff.

Another expedient would be the installation of a number of exchanges in different parts of a town. But this would only fulfil its purposes if all those subscribers who communicate most frequently with one another belonged to the same exchange. Further, by the multiplication of exchanges the prime cost, and also the working expenses, would be enormously increased, the subscription would have to be raised accordingly, and the working would not pay.

The only practical solution of all these difficulties has been found in the employment of the multiple switch-board, which is dealt with in a subsequent chapter.

CHAPTER XVI.

TELEPHONE EXCHANGES.

THE FRENCH SYSTEM.

139. THE telephone in France is managed by the Société Générale des Téléphones, to which the State in 1879 granted a concession of five years. This concession ended the 8th Sept., 1885, and was renewed to the same Society for a similar period and on the same conditions. The Company, for such rights, pays to the State 10 per cent. of its gross receipts, and to the Municipality of Paris the same percentage for the right of running the telephone cables in the city sewers. This concession does not constitute a monopoly to the Company, and the State has reserved to itself the right of buying up the plant, at any time of the concession, at a price to be fixed upon by experts. These conditions are certainly far from being favourable to the extension of the telephone in France. In fact, the business is now divided between the State and the Company as it is in England between the Post Office and different Companies. The State is running telephone exchanges in nine towns, with a total of 1,062 subscribers, and the Company in eleven towns, with a total of 6,113 subscribers.

The rate charged by the State is £8 inside the town boundary, and four shillings for every 200 mètres beyond. The subscriber has to pay the cost of his line and instrument. No night service is provided.

In Paris the Company charges £24 per annum for one circuit, £22 each for two, or £20 each for three circuits. In other cities £16 is charged for one circuit.

THE EXCHANGE SYSTEM IN PARIS.

140. The whole Paris network, in order to avoid all trouble from telephonic induction, has, like the Post Office system in England, been from the beginning installed with insulated wires in cables and it consists entirely of metallic circuits. The cables are placed in the city sewers. Paris having the most complete system of sewers, the adoption of an entirely underground system is thus much facilitated.

The laying of the cables is not done by the Company; it is under the care of the Administration of the State Telegraphs, whose experience in laying telegraph cables in the sewers has been a great help to the Company (all the State telegraph cables are also laid in the city sewers).

The Company has to re-imburse the State for the total expenses of laying the telephone cables in the sewers, and is charged 5 per cent. more for general expenses.

For each subscriber the Company has to furnish the Administration of the State Telegraphs with a plan of the sewers which the cables must follow, and with the indication of location of the subscriber.

The cables are suspended by hooks fastened into the stones of the sewer vaults. Each cable contains fourteen conductors, forming seven metallic circuits. The conductors are formed of three copper strands twisted together and covered with a layer of guttapercha, and afterwards by an envelope of coloured cotton. The electrical resistance of the conductors is about 48 ohms per mile. The conductors are of seven different colours —white, blue, yellow, maroon, red, black, and green. Each pair of conductors of the same colour, serving for a single subscriber, is lightly twisted together; the seven pairs are afterwards also lightly twisted together and formed into a rope, which is then covered with strong linen tape, and drawn into a lead pipe. The double twisting eliminates all the effects of mutual induction (§83). Each cable is numbered throughout its entire length, and it is thus easy to find any cable when it is necessary to make repairs or to change connections.

141. The cables are run from the central office and stopped as near as possible to a group of seven, or less, subscribers. Each of these is then reached by small cables of one pair of conductors, bound to the principal cable by means of a joint protected by a lead cover. The conductors not utilized in the cable of fourteen conductors remain disconnected.

In the sewers where factories are allowed to empty the hot water proceeding from the condensation of steam, it is necessary that the cables should be insulated with india-rubber instead of guttapercha.

The operation of entering the house of a subscriber is a very easy one. Nearly every house in Paris has its own sewer, which commences at the side of the house itself and stops at the main sewer. All sewers in Paris, except the main collectors, are under the side walks. The collectors are generally under the roadway; they are, in fact, small rivers, into which all the main sewers empty.

The small cable is brought, suspended on hooks, from the extremity of the cable of fourteen conductors into the particular sewer. To get it to the outside a hole is made close to the side of the house, and directly over the roof of the particular sewer. In this hole a perpendicular gas-pipe is inserted, and the small cable is run alongside the front of the house till it reaches the frame of the window of the room where the apparatus is to be

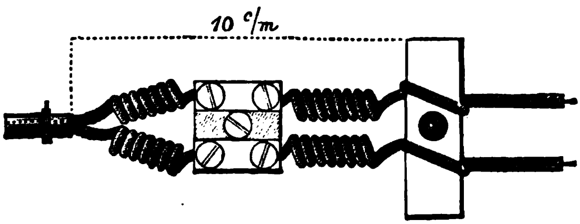


FIG. 159.

placed. Fig. 159 shows how the small cable is connected with the interior wires.

It sometimes happens that a subscriber has to be reached who has no sewer in his street. In that case the small cable is run as near as possible to the subscriber's house by the way of the sewers, and from the particular sewer of a house alongside the front of it up to the roof, and from the top of this house two air lines are erected in prolongation of the underground cable of the conductors to the subscriber's house by means of small poles attached to the roof. This, however, very rarely occurs.

There are in Paris about 40 miles only of overhead wires (metallic circuits), against 4,500 miles of underground metallic circuits in cables.

142. The single wire system, with an earth return, is

employed only in provincial cities, where also most of the lines are overhead.

The results of the use of metallic circuits in the Paris underground system, as in England, are most satisfactory. The lines are entirely free from telegraphic or telephonic induction.

In the sewers where telegraph cables are running, the telephone cables are laid generally on the opposite side. Hitherto no electric light cables have been allowed to be laid in the city sewers.

The city has been divided into twelve telephonic districts, having each a central office, to which the subscribers inside of the limits of the district are connected.

The total number of subscribers in Paris is now (October, 1888) 5,792, distributed between the twelve exchanges. These twelve central offices are connected together by 424 auxiliary lines, most of which converge to the central office in the Avenue de l'Opéra, to a switchboard of a peculiar form. This switchboard is required to distribute the trunks between the different offices, according to the frequency of connections asked between these, and also to enable the testing of all the trunk and subscribers' lines to be carried on from one central point. For that purpose a Thomson galvanometer, with all its accessories, is established in a laboratory close to this switchboard. An electrician is specially in charge of the testing of the cables of the whole network, so as to localise faults and to enable repairs to be made.

The total length of the auxiliary lines is 1,200 miles of metallic circuits.

All the central offices are built on the same system. We shall describe the central office A, No. 27, Avenue de l'Opéra, which is one of the largest.

143. The cables which connect subscribers to the central office enter by a short and spacious branch from the principal sewer running under the side-walk of the Avenue de l'Opéra, and arrive upon a level with the basement of the central office.

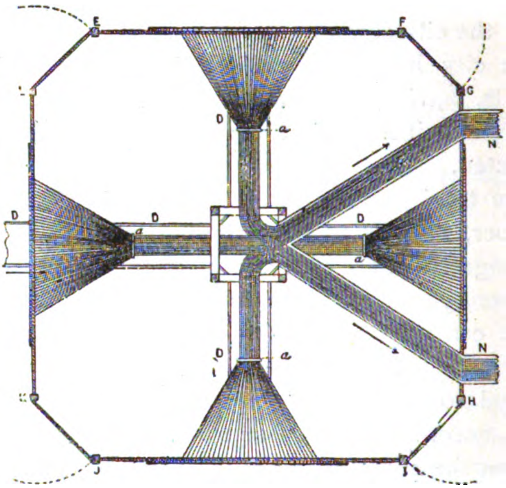


FIG. 160.

A plate of bronze, fastened to the wall by means of bolts, is perforated by a sufficient number of holes to permit the admission of the cables into the basement of the house.

Two hundred and fifty cables, furnishing 1,750 metallic circuits, are thus brought into the basement of the central office.

These cables are carried upward and downward to

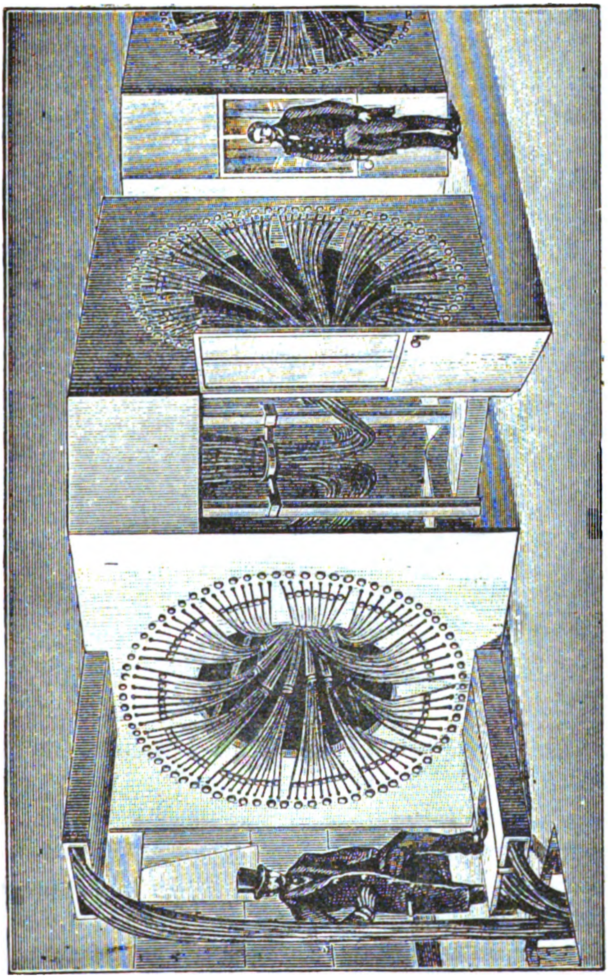


FIG. 161.

the four back faces of a switchboard similar to the one spoken of above.

This switchboard is in the form of a square wooden chamber of about 3 yards in height, having four cut angles with doors to enter from all sides. Each of the faces of this chamber presents a large circular hole. The cables are distributed inside of the four faces of the chamber all around the circular holes in the form of rosettes. Fig. 160 is a plan of this chamber, and Fig. 161 a perspective view.

The lead cover of the cables being cut off, the seven pairs of conductors are brought separately to the out-

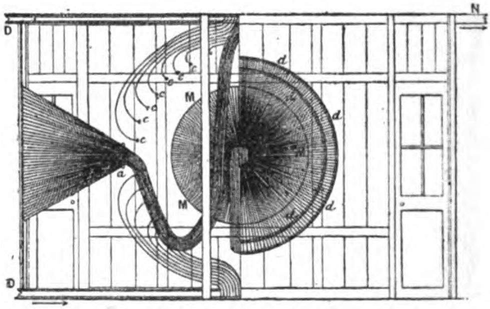


FIG. 162.

side faces through small holes *c c c c* to double terminal plates *d d d d* (Fig. 162).

Each of the seven pairs of conductors is braided with coloured cotton of a different colour, and an ivory counter attached to each pair indicates the name and address of the connected subscriber. Each hole, through which a cable is passed, is numbered with the number that the cable bears throughout its length in the sewers. Fig. 163 shows on a larger scale the arrangement above described.

To each double terminal plate *d d* is connected a small cable *e* of two conductors, insulated with cotton and paraffin. These cables are brought in bundles N N (see Fig. 160) up into the central office at the back of the switchboard, and connected to the switch-holes. The four holes MM MM (Fig. 162) may be considered as the bases of four conic spaces having a common centre, which is the geometrical centre of the chamber. This is to get all the cables to pass by that centre, so that they should have all the same length and might be interchanged. The cables are supported in the interior of the

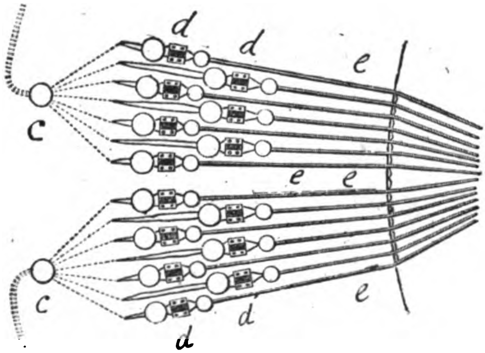


FIG. 163.

chamber by iron rings, and hang quite loosely beneath the rings till they enter into the wooden troughs N N.

This arrangement in form of rosettes permits of an easy testing of the line from the terminal plates *d d*, *d d*, and the classing of the subscribers at the switchboard according to the frequency of their demands of connection or other conveniences, as all the cables are of the same length, and can therefore be easily changed from one pair of terminal plates to another.

144. Fig. 164, which is a cross-section of the switch-board, shows that it is composed of two similar switch-boards, back to back, separated by a passage, in which the cables are brought in the wooden trough N, grouped in bundles each of twenty-five cables of two conductors. The two conductors are insulated with different coloured cotton—blue and red—and are braided together. The

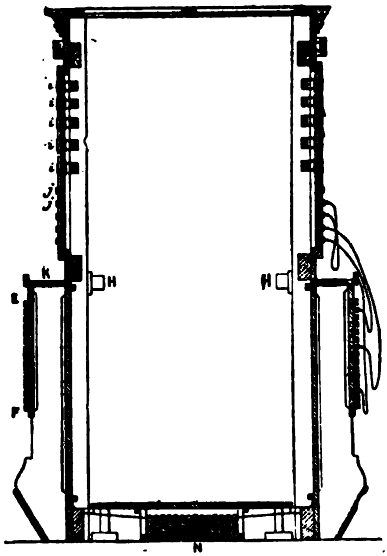


FIG. 164.

passage is to allow the linemen to get to the connections and annunciators at the back of the switch-board.

Since the first establishment of central stations, numerous improvements, devised by Mr. A. Berthon, the present Director of the Société Générale des Téléphones, have been put on trial, and, having proved

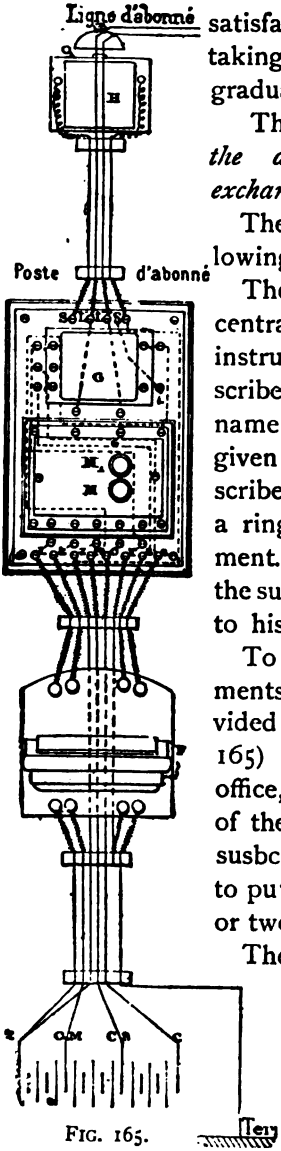


FIG. 165.

satisfactory, the Company is now taking steps to introduce them gradually into their system.

This improved system is called *the direct call system for telephone exchanges.*

The principal features are the following :—

The subscriber ringing up the central office need not wait with the instrument at the ear till the subscriber asked for answers. Once the name or number of this subscriber is given to the operator, the calling subscriber may hang up the receiver till a ring calls him back to the instrument. This ring is a direct call from the subscriber asked for, who has come to his instrument ready to speak.

To effect this, each set of instruments at the subscriber's office is provided with two call keys, M M_1: (Fig. 165) one is for calling the central office, the other for the direct calling of the correspondent with which the susbcriber has asked the central office to put him in connection through one or two central offices.

The direct call, of course, does not drop any of the clearing-out annunciators. Fig. 165 shows a complete set at a subscriber's office.

Z C is the battery, composed

of nine Leclanché cells, three cells on the microphone, and the nine cells altogether for *calling* the central office, or for *direct call*. F is the transmitter, M and M_1 the two special call keys, G is a relay of 400 ohms resistance, closing the local circuit of the bell H. The local current for the bell is also furnished by the nine Leclanché cells.

Subscribers being enabled to ring up one another by the special key M_1 when once they are notified, through the central offices, that they are connected, any delay in answering can then be only ascribed to the called subscriber, and not to the operators at the central office.

Subscribers once connected can remain connected as long as they desire, and carry on their conversation without being overheard by the central office. They can also call another subscriber at any time by ringing up the central office with the proper key M.

The Company supplies, at the rate of £11 5s. per mile per annum auxiliary trunk lines to accommodate subscribers desirous to have permanent connections between two offices, or house and office, where these are connected to two different central offices. There is no extra charge, of course, for subscribers desiring permanent connections when they are connected through the same central office.

Many subscribers of the Paris exchange have their factory and stores so connected permanently, to save time in getting through. These permanent connections also save part of the work at the central office.

145. The principle of the direct call system will be easily understood from the following diagrams, showing the calling, the speaking, and the clearing-out circuits.

Fig. 166 shows the calling circuit from subscriber P to the central office: *l l'* is a metallic circuit running from the subscriber to the central office, through the switch and annunciator *a*, which has a resistance of 400 ohms; *c c'* are the two springs of the call key M, for calling the central office; *b b'* are the two contacts, with the battery Z C of nine Leclanché cells. The springs *c* and *c'* are insulated one from the other by a piece of

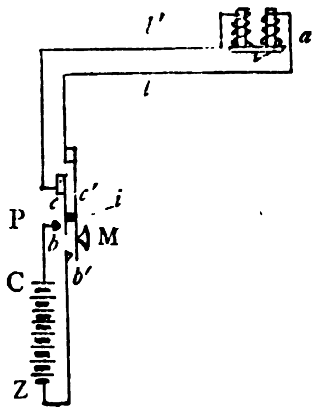


FIG. 166.

hard rubber, *i*, fixed on spring *c*. By depressing the push button M, the current of the battery Z C is sent into lines *l l'*, through the annunciator *a*, calling the attention of the operator at the central office. The operator, in answer to the call, inserts a plug, with contacts, into the switch-hole to which the lines *l l'* are connected before going through the coils of the annunciator *a*. This plug is connected by a flexible cord with a complete apparatus, having a call key and office telephone combined, which is thus thrown in circuit with the lines *l l'*.

Fig. 167 shows the calling circuit enabling the operator to answer the subscriber's call. The operator, being informed that subscriber Q is wanted, will call him up with the special key C (Fig. 167), composed of two springs *c c'*, which, by the depression of the push-button

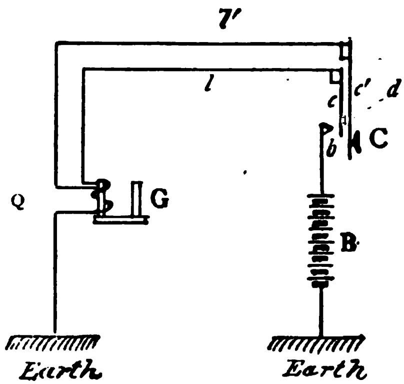


FIG. 167.

C, are put in contact one with the other by a metallic piece *d*, fixed upon the spring *c'*, and also connected through the contact *b* to battery B, composed of ten Leclanché cells, the other end of which is to earth. By means of the telephone lever-switches, one end of the coil of the relay G at the subscriber's office is connected to both the lines *l l'* (Fig. 167); the other end of the coil is put to earth. The depression of the push-button C at the central office, which connects both springs *c c'* with one end of the calling battery, therefore sends a current through both lines in the same direction, which, passing through the coils of the relay G at the subscriber's office Q, actuates the relay and closes the local circuit of the bell H (Fig. 165).

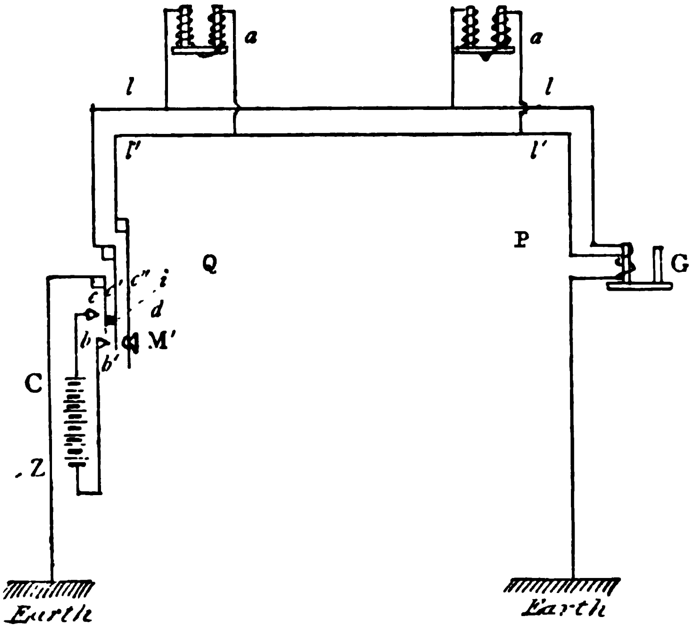


FIG. 168.

The subscriber Q being thus called up, the operator establishes a connection with a flexible cord between his switch-hole and that of the subscriber P (Fig 168), who asked for him.

The called subscriber answers by depressing the direct call key M' of his instrument.

This call will go straight to the instrument of the calling subscriber, and ring his bell by closing the relay G, and will also go through the central office without dropping the annunciators *a a* of the two subscribers connected. Fig. 168 shows this calling circuit.

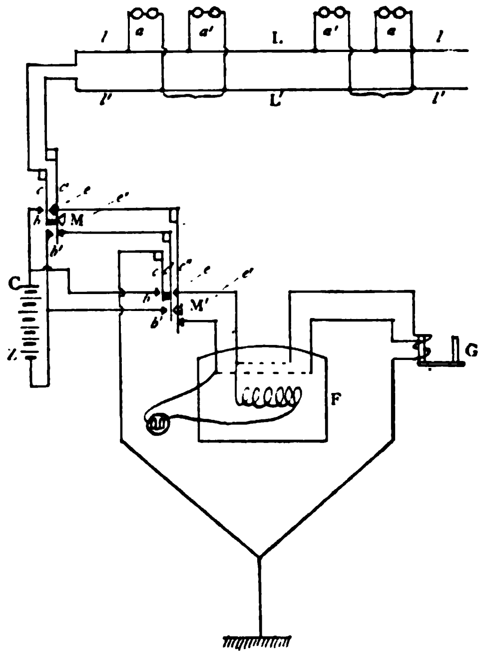


FIG. 169.

The direct call key M′ is composed of three springs, *c c′ c″*; *c′* and *c″* may be brought in metallic contact by the metallic piece *d* fixed upon *c″*, when the button M′ is depressed; *c′* and *c* are insulated one from the other by a hard rubber piece, *i*, fixed upon *c′*. By pressing the push button M′ the springs *c* and *c′* will make contact with *b* and *b′*, and the current of the subscriber's battery Z C will pass through the relay G on both lines *l l′* at the same time, not dropping, consequently, any of the annunciators *a a* left "in bridge" at the central office.

146. The speaking circuit (Fig. 169) is an entirely metallic one, the earths connected with the relays G G at both subscribers being cut out when talking by the switch-levers of the subscribers' instruments, and the earths of the direct call keys being also out of the circuit.

The speaking circuit is, therefore, as shown in Fig. 169, from the lines *l l′* to the springs *c c′* of the key M, through the upper contacts *e e′*, through the springs *c′ c″* to the upper contacts *c e′* of the direct call key M′ to the line terminal screws of the instrument F, through the secondary of the induction coil, and through the telephone receiver.

Two annunciators, *a a*, are left in derived circuit as clearing-out annunciators, if the connections are made between two subscribers connected to the same central office; but if an auxiliary line, L L′, joining two central offices, is used, the annunciators *a′ a′* at the ends of the trunks at each central office are also left in derived circuit as clearing-out annunciators.

In the same office connections between the switch holes are made with flexible cords when they are on the same board, but when the subscribers' switch-holes are distant one from the other local auxiliary lines are used.

When the two subscribers have finished their conversation they can, by depressing call key M, send the current from their battery of nine Leclanchés to line, and can thus drop the clearing-out annunciators *a a'* of their respective central stations.

147. The following diagrams of the clearing-out circuits permit of calculating the strength of the derived currents through the clearing-out annunciators :—

Supposing two subscribers connected through one central office X (Fig. 170), and the resistances of the lines to be $ll = 50$ ohms, $l'l' = 25$ ohms, two annunciators of 400 ohms each are left on derived circuits. Subscribers

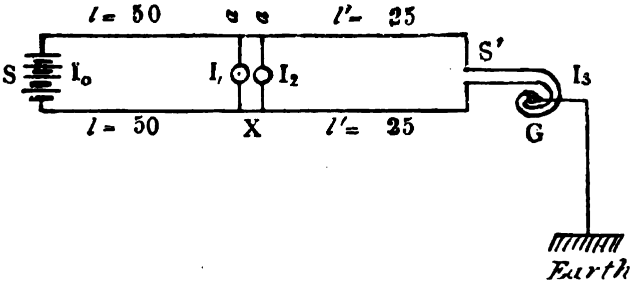


FIG. 170.

being instructed not to fail to ring off when they have finished their conversation, we shall suppose that subscriber S has rung off with the current of the battery of his instrument—nine Leclanché cells.

The currents in each of the derived circuits—annunciators I_1 and I_2—will be—

$$\frac{13{,}500 \text{ (milli-volts)}}{100 + \cfrac{1}{\cfrac{1}{400} + \cfrac{1}{400} + \cfrac{1}{450}}} \times \frac{\cfrac{400 \times 450}{400 + 450}}{400 + \cfrac{400 \times 450}{400 + 450}} \text{ milli-ampères.}$$

that is 19·6 milli-ampères through each, which is quite sufficient to drop the clearing-out annunciators.

Fig. 171 supposes two subscribers S S′ connected through two central offices X Y joined together by an auxiliary line L L′= 300 ohms resistance. The currents in each of the derived circuits I_1 I'_1 in this case will be about 19·5 milli-ampères.

The current sent by the battery of subscriber S will drop the two clearing-out annunciators at the central office X, and the current of about the same

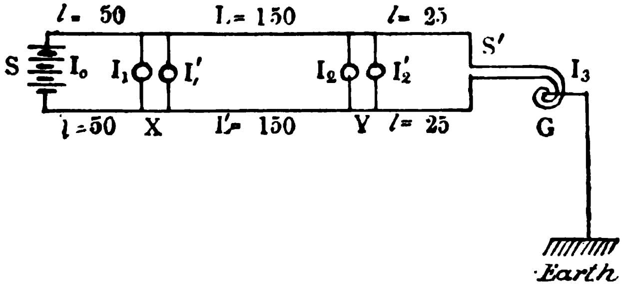


FIG. 171.

strength sent by the battery of subscriber S′ will drop the two clearing-out annunciators at central office Y. The lines will be cleared out at the four boards at once.

148. From the above explanations and figures it is easy to understand that the application of the direct call system to a large telephone exchange system, comprising *any number* of branch or central offices, is based on the principle that the annunciators left on derived circuits should be wound with high resistances, such as 400 ohms, so as not to weaken speech; that they

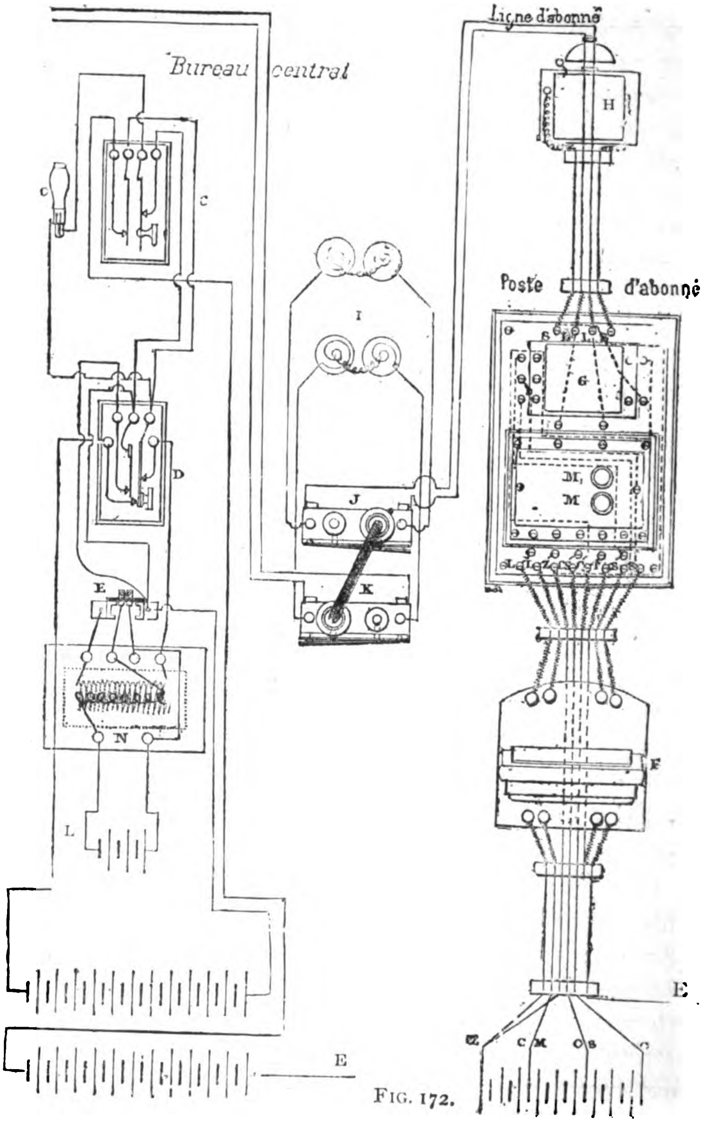

Bureau central
Ligne d'abonné
Poste d'abonné
C
C
D
E
N
L
E
I
J
K
H
G
M
M
F
E

FIG. 172.

are dropped by calls made on metallic circuits, and are never dropped by calls made on earthed circuits, no current at all, or only a very weak current (if the two branches *l l* of the line are of unequal resistance) going through the derived circuits formed by the annunciators in that case. In practice, it is found that one of the branches of the line must be direct to earth to prevent the working of the system. It is,

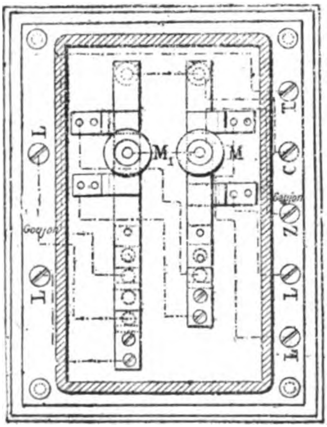


FIG. 173.

therefore, a sign that one of the lines is earthed or nearly so, when the direct call works wrong.

149. Now that the principle of the system has been fully explained, Fig. 172, which represents the connections established through a central office between two subscribers having the necessary sets of direct call instruments, will be easily understood: Z C is the calling battery of nine Leclanché cells. Z CS is for the local circuit of the bell H when closed by the relay G.

Z CM shows the local circuit for working the microphone.

The earth wire is connected with the relay G and key M_1; F is the subscriber's instrument (the Ader microphone and receiver, which are generally employed in the Paris exchange); M is the key for calling the central office; M_1 is the direct call key; H is an ordinary bell of 5 ohms resistance, controlled by the relay G.

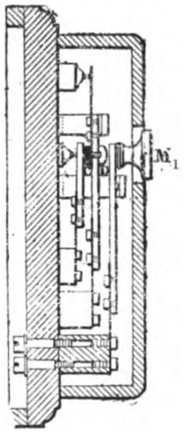


FIG. 174.

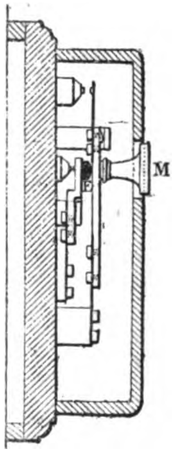


FIG. 175.

Fig. 173 is a plan of the double call key M M_1. Fig. 174 is a section of the direct call key M′; Fig. 175 is a section of the call key M to the central office.

At the exchange the subscriber's line is connected at the back of the switchboard to a switch-hole composed of two metallic plates, insulated from one another by a thin plate of ebonite, and placed back to back. In the front plate arc two holes, which extend across the ebonite into the back plate, where they are of a smaller size. These two plates are tightly fastened together by two screws, which serve also to fix them on the board.

Fig. 176 shows the details of a subscriber's switch-hole and the way the lines and the annunciators are connected with the two plates: *a* is the annunciator; *l l'* the subscriber's lines; *r r*, *r r* are springs made of steel

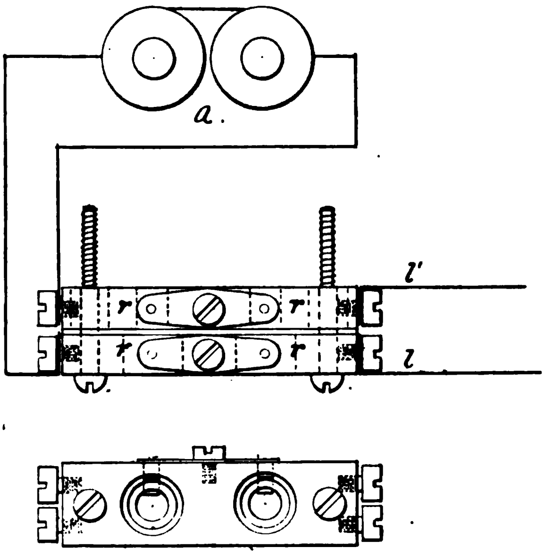


FIG. 176.

with gudgeons of silicious bronze wire to insure the contacts of the plug when inserted in the holes of the plates.

Fig. 172 shows also the connections of the switch-holes with the auxiliary lines and annunciator. These switch-holes are constructed in exactly the same way as those for the subscribers' lines, but the two metallic parts are tightly fastened together by two screws A and B, Fig. 177, which extend to the back of the board, not only as a means of fixing, but also to make connections with the annunciator. The screw A is completely insulated from the metal of the two plates, except at one point, where a small pin permits the establishment of communication with the spring above (C, Fig. 178). Screw B is insulated from the front plate, but communicates with

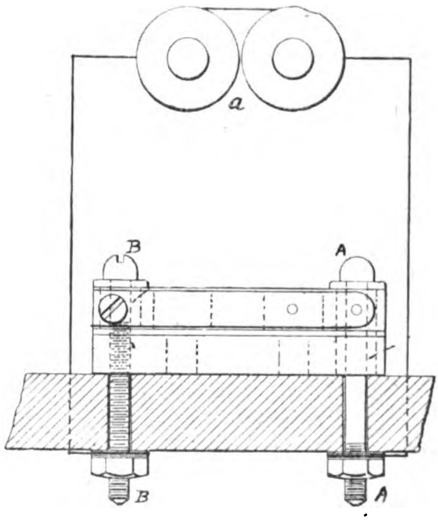


FIG. 177.

the back plate. The two plates each communicate with one of the lines, and the annunciator connected with the two screws A and B remains in the circuit of the auxiliary line as long as the spring maintains the contact between the anterior plate and the annunciator; but the annunciator will be cut out of circuit as soon as a plug, inserted in the right orifice of the switch-hole, will have left the spring.

The plug O, Fig. 172, connected with the keys C and D, and with the special switch-hole E, is intended to place the operator's apparatus (the combined Berthon-Ader telephone) in communication, through the main switch, with the subscriber or line switch-holes, or through the auxiliary line switch with the operator at the other end of the auxiliary lines. Similar plugs are used at the extremities of the flexible cord employed to connect subscribers together. Fig. 179 shows the plug. The part *a* is very carefully insulated from the part *b*

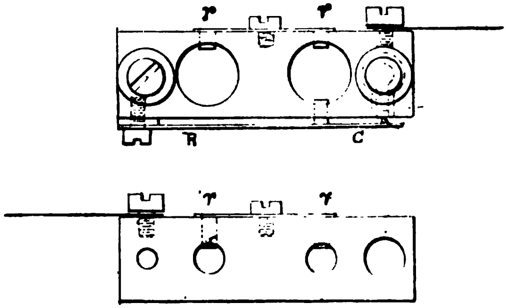


FIG. 178.

by means of ebonite. Each of the parts *a* and *b* is connected with one strand of the flexible cord, which consists of two conductors in the form of two spirals insulated with cotton, and braided together with a silk covering.

The plug, when introduced into one of the orifices of the switch-hole connected with the subscriber's lines, makes contact, part *a* with the back plate, part *b* with the front plate, but leaves the annunciator on a derived branch of the circuit; and, when a call is made at a subscriber's office, with plug O and with key C (Fig. 172), the current being from an earthed battery, the annunciator does not drop.

The plug inserted in the left-hand hole will leave the annunciators in derived circuit. Connections are always made in that way; but calls are made by inserting the plug in the right-hand hole, so as to cut out the annunciator.

The calls from the central office are made with two different keys. Figs. 180 and 181 represent the key C (see

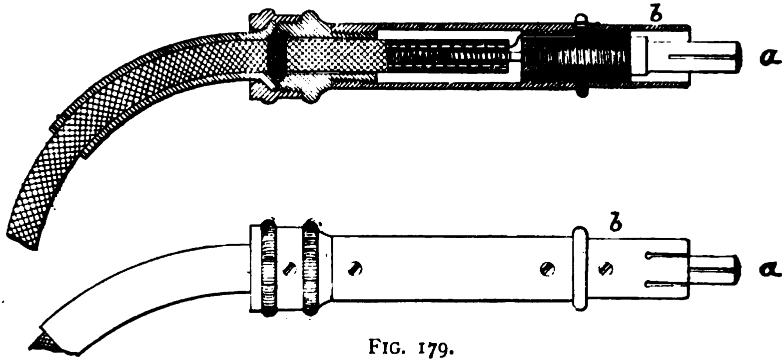


FIG. 179.

Fig. 172), which is in connection with an earthed battery of fifteen Leclanché cells. This key is for calling subscribers only. Its connections can be followed on Fig. 172.

Figs. 182 and 183 represent the key D for calling on auxiliary lines to make connection between subscribers belonging to two different central offices. Its connections also can be followed on Fig. 172.

The key C is used only at the main switchboards, and the key D only at the boards to which auxiliary lines are connected.

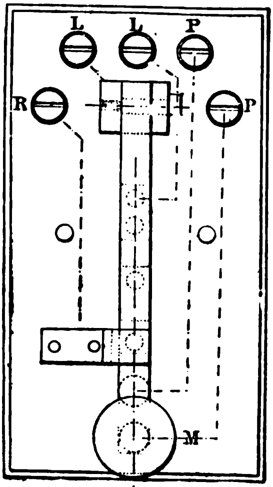


FIG. 180.

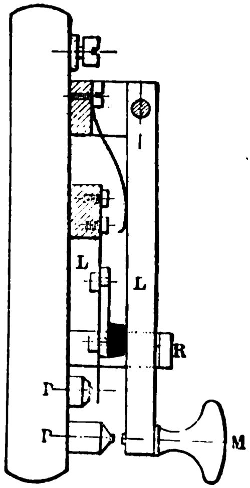


FIG. 181.

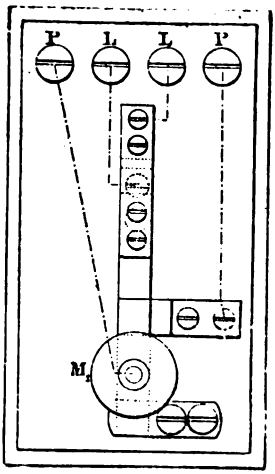


FIG. 182.

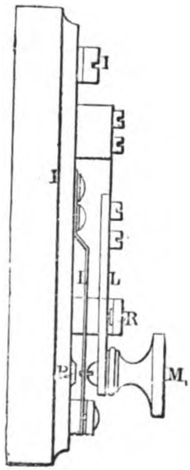


FIG. 183.

E (Fig. 172) is a special switch-hole, with four contacts, which is to enable the operator to throw his speaking apparatus on the subscribers' or auxiliary lines, and to answer or repeat calls. N is the induction coil of the operator's speaking apparatus.

150. The Berthon transmitter (a modification of the Moseley, § 52) has now replaced the one described in § 47. The form adopted consists of two circular carbon plates P P′ (Fig. 184) 1·5 mm. thick and 60 mm.

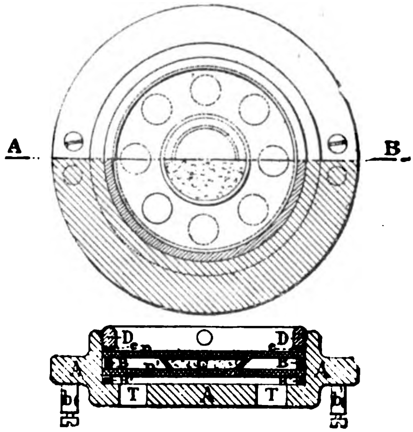


FIG. 184.

diameter, separated from one another by the india-rubber ring B. An ebonite cupola, C, three-quarters filled with granules of retort carbon, is placed in the centre of plate P′ When the apparatus is suspended, the granules press against the exterior plate P, and establish microphonic contact. The whole is enclosed in an ebonite case, A, in the upper part of which is an opening corresponding in diameter to that of plate P; a metal ring, D, fitted into the opening, keeps the plate P in position. The bottom of the case is pierced by holes, T T, which enable the lower plate, P′, to vibrate freely; and the terminals, *b b′*, are likewise fixed to it. The contacts of the terminals with the carbon plates are effected by means of slightly flattened platinum wires. A second india-rubber ring, B′, separates P′ from the bottom of the case.

The most favourable angle at which the plates should be inclined is 50°, and it is stated that in this position the apparatus is most sensitive, besides being free from the disagreeable crackling noise often met with in other apparatus.

A battery (L Fig. 172), of three cells is employed on each operator's combined telephone: A is the calling battery for auxiliary lines—twenty Leclanché cells; B is the earthed battery of fifteen cells, for calling subscriber.

151. The average number of calls per day in Paris is 25,000, giving an average of 4·32 daily calls per subscriber. About 65 calls out of 1,000 are given between subscribers connected at the same central office; 935 have to be given through two central offices.

Each operator with the present system answers about 175. This number of calls corresponds to about 300 connections made by each operator.

It is expected that when the direct call system is applied generally throughout the Paris Telephone Exchange system, each operator will be able to answer at least 350 calls.

Each subscriber has a battery of nine Leclanché cells, three of which are used for the transmitter, and the total number for the call and clearing-out signals. The three cells on the microphone have to be renewed every four months regularly; but the six other cells are found to last from eighteen months to two years, and even more. The maintenance of the 50,000 cells actually in use requires great attention, and is done in the most regular and economical way.

The longest auxiliary line in the Paris system is 10,000 mètres, or 6·2 miles; and the shortest is 1,350 mètres, or ·8 mile.

The resistance of the wires of the cables is about 48 ohms per mile. If we suppose two subscribers at a distance of one mile each from the central office, and corresponding through an auxiliary line of 6 miles, the resistance of the metallic circuit will be 48 ohms × 2 × 8 = 768 ohms.

The speaking on these long lines is quite satisfactory, even with two annunciators left in derived circuit at each central office.

Numerous experiments have been made concerning the greatest practical distance of talking on the underground metallic circuits of the Paris Exchange, and it has been found that the talking is still quite practicable on metallic circuits of 16 miles length between two subscribers or 32 miles of metallic circuit, representing 1,536 ohms resistance; provided, however, that no derived circuits exist at the central offices.

One of the advantages of the direct call system which has not yet been pointed out is that by using an earth circuit for calling, instead of a metallic one, the resistance is only one-fourth, and that, therefore, much less battery power is required. With the nine calling cells at the subscriber's office, the direct calls are made without any difficulty between the farthest points of the network, which extend beyond the fortifications.

It may be pointed out that the direct call system might be worked just as well with magneto call instruments, and that it is also applicable to exchanges worked on earth circuits. In this latter case polarised annunciators and polarised relays to work the bells at the subscribers' offices are employed.

CHAPTER XVII.

TELEPHONE EXCHANGES.

THE SWISS SYSTEM.

152. THE switchboard used is shown in Fig. 185. On a small table, D, are ten movable plugs, and in front of them two rows of contact keys, one of five and the other of ten keys. At B are fifty plug-holes, arranged in five vertical rows of ten each. At A are fifty annunciator discs, which fall when the armature is attracted by the electro-magnet. (The discs 8, 12, 34, 46 are shown in this latter position.) Five annunciators of similar description are fixed beneath the switch-holes at C.

The annunciator is shown in Fig. 186, which is two-thirds full size: *e* is the electro-magnet with two coils, the resistance of which varies from 90 to 100 ohms; *d* is a soft iron plate carrying a series of five electro-magnets; *l* a support carrying the armature and a thin horizontal arm, *b*, terminating in a small hook. When the armature is not attracted this hook arrests the disc *a*, which, as soon as the hook is lifted, through the attraction of the armature, falls by its own weight. The disc, on falling, strikes against the stop *g*, and makes sufficient noise to be heard in all parts of the operating room; at the same time it pushes the spring *f*, fixed to the plate *c*, against the screw *h*, which is insulated by a piece of ebonite, *i*. The spring closes an independent and local circuit, in which are a battery, a call bell for the night, and a pole-changer for the day.

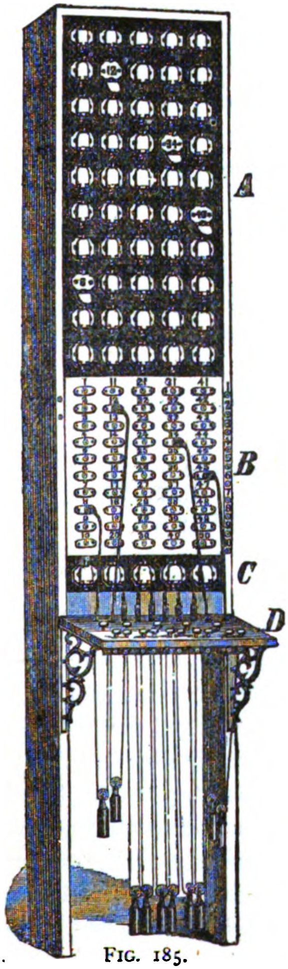


FIG. 185.

Each of the fifty plug-holes (at B, in Fig. 185) is a sort of Morse manipulator with three contacts; that is to say, that, by introducing one

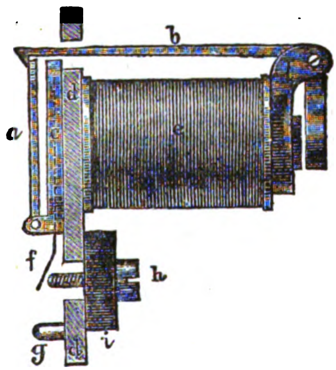


FIG. 186.

of the ten plugs into a hole, one circuit is interrupted and another simultaneously established.

Fig. 187 shows one of these plug-holes in longitudinal section. From each plug-hole a metallic stem extends through the switchboard to a threaded portion, *e*, provided with two nuts, *f*, *g*, having contact washers between them, which serve to provide for connection with the subscriber's line. The nut *f* also serves to hold the end of a bent spring *c*, the free end of which normally bears against the point of a screw, *h*, passing through a piece of ebonite. This screw is connected with the electro-magnet of the annunciator corresponding to this plug-hole, the other end of the electro-magnet being connected to earth. As long as no plug is inserted in the plug-hole, the annunciator is included in the circuit of the subscriber, the circuit from the line being through the spring *c* and screw *h*. But when a plug is inserted in the hole, the spring is disconnected from contact

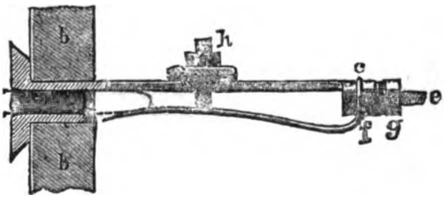


FIG. 187.

h, while the plug itself forms a contact with the spring, and consequently with the line wire connected at *f*, *g*. By means of the connecting cord attached to the plugs, the line may be connected to another line by inserting a plug into the switch-hole corresponding to the line in question, provided the two plugs are connected together.

The contact keys (Fig. 185) are merely of the ordinary form, and need no special description. Those in the row of five keys, simply make contact between two points which otherwise would be insulated, whilst the keys of the other row act like telegraphic manipulators, by interrupting one circuit in order to establish another.

The parts A and B (Fig. 185) are completely independent of the parts C and D of the switchboard; but in these two latter parts there are five systems, each forming a complete and distinct whole, quite independent of the others. Each system comprises one of the annunciators of C, the two plugs which are nearest to this

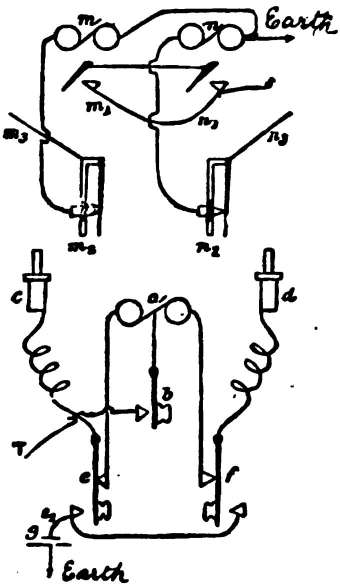


FIG. 188.

annunciator, the two contact keys immediately in front, and the single contact key behind and between them.

153. In order to explain the operation of a switchboard of fifty subscribers, we will take any two subscribers wishing to communicate with one another. Let m_3 and n_3 (Fig. 188) be the subscribers' lines, m_2 and n_2 their respective switch-holes, *m*, *n* the coils of the corresponding annunciators,

a any one of the annunciators in part C, *c* and *d* the plugs resting in front of this annunciator, and *b*, *e* and *f* the contact keys belonging to this system; T is the telephone belonging to the switchboard, *g* a battery for ringing up the subscribers. Key *b* is, therefore, the telephone key; the others are for calling. It is easy to follow the path of the current for each position of the movable pieces. Let us suppose m_3 to have sent a current. Disc *m* falls, the central station places the plug *c* into the plug-hole m_3. At this moment all communication of the subscriber m_3 with the central station is interrupted, but it suffices to press the key *b* to communicate by telephone T with m_3. The operator announces his attendance by the word "*Voilà*" (I am here). The subscriber m_3 expresses his wish to communicate with n_3. The operator places the plug *d* into hole n_2 and presses the key *f*, thus calling the subscriber n_3. A moment after the operator presses the key *b* to find out whether n_3 is in attendance. If he is, the two subscribers are placed in communication without any further operation. In case n_3 does not reply, the operator presses a second time the key *f*, and listens again. As soon as the called subscriber has answered, communication with the caller is established through the annunciator *a*. When one of the two subscribers gives the signal of the end of the conversation, the annunciator falls, indicating thereby that the plugs *c* and *d* ought to be withdrawn. At m_1 and n_1 is shown the circuit for the night call. The bell and battery, with the pole-changer, are joined up between *s* and earth.

When in a central station the switchboards exceed a certain number, two subscribers can no longer be directly connected. Means for connecting the different switchboards with one another must be adopted for this purpose. On the right-hand side of part B (Fig. 185) will be noticed ten marginal plug-holes, numbered one to ten, and all the holes of the same number in all the switchboards are connected together by conductors. Consequently, in order to connect two switchboards together, it is only necessary to insert a plug into the same number at both switchboards. Let us suppose, for instance, that subscriber 27 wishes to speak to 752. At the first switchboard, which contains the numbers 1 to 50, two plugs of a pair are inserted, one into plug-hole 27 and the other into the marginal plug-hole 1. At the switchboard, which contains the numbers 751 to 800 a similar operation is performed with regard to the plug-hole 752, and the marginal hole 1. Communication is now made, but four plugs, six contact keys, and two annunciators are engaged. In order to simplify the proceedings, one cord with two plugs is used at the called subscriber's board. The effect is the same as if the two subscribers were on the switchboard containing the numbers 1 to 50. The number of marginal plug-holes might easily be increased, but practice has shown that ten simultaneous communications are sufficient to satisfy all requirements.

154. Two call systems were originally used in Switzerland. At Bale, direct battery currents were at first employed, whilst at all other stations alternating currents were used. These alternating currents are produced by a special automatic apparatus shown in Fig. 189. At the top will be seen a strong magnet, to which is attached a pendulum. This latter is set in motion by two bobbins of a polarised electro-magnet, the cores of which show the same polarity, whilst the

pendulum is of opposite sense. On a plate are mounted two systems of contacts; one of these regulates the oscillations of the pendulum, whilst the other serves for the reversal of the current. Fig. 190 illustrates the principle of the apparatus: *d* and *e* are vertical sections of the pendulum close to the two contacts. The battery current passes from the terminal *b* to the bobbin *i*,

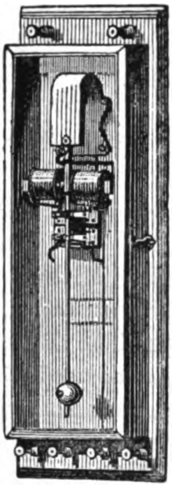


FIG. 189.

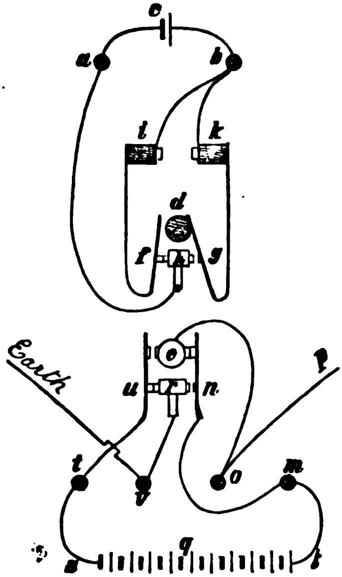


FIG. 190.

through the spring *f*, and the rigid piece *h*, and thence by *a* to the battery *c*. Bobbin *i* thus attracts the pendulum rod, and, in consequence of this attraction, *d* breaks contact between *f* and *h*, and establishes a new contact between *g* and *h*. The current now passes through bobbin *k*, and the pendulum again takes up the position represented in the sketch, to continue its oscillations in the manner described. The battery *c* should consist of two constant cells.

Section *e* of the pendulum shows the variations of contact which occur at the springs *u* and *n*. When the pendulum swings to the right, the rigid piece *r* makes contact with the spring *u*, and the rod with the spring *n*. The positive current starting from pole *t* of battery *q* passes through *m*, *n*, rod *e*, and terminal *o*; and the negative current starting from *s* goes to spring *u*, piece *r*, and terminal *v*, and thence to earth. In the opposite position of the rod the negative current arrives through *t*, *u*, *e*, *o*, *p*, and the positive current goes to earth through *m*, *n*, *r*, *v*. The battery *q* consists of Lechanché cells, whose number depends on the extension of the network.

The telephone apparatus used by each operator in the central office requires no special description. It consists of a transmitter supported at a height convenient to the operator's mouth, and above this is a supporting device for the receiver, which is so disposed that it permits a large range of motion, to adapt it to any position preferred by the operator.

INTERMEDIATE OFFICES.

155. It often happens that the subscriber wishes to be in communication with the central station, and at the same time with some other part of the town. This is the case, for instance, of a merchant whose house is at some distance from his office, and who wishes to communicate from one to the other, and also from either with the central station. This is done by extending, as far as

the house, the line connecting the Central station with the office, or *vice versâ*, and thus obtaining two stations worked by one line.

The Swiss Telephone Administration encourages such arrangements by reducing the amount of the subscription, and it is highly appreciated by the public, and extensively employed.

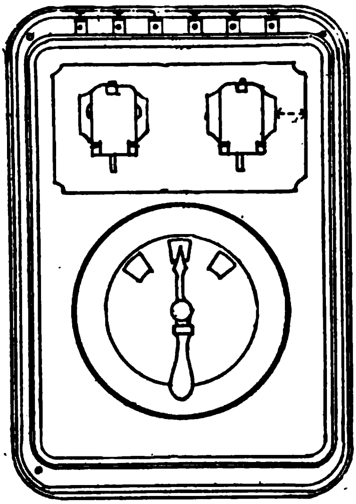


FIG. 191.

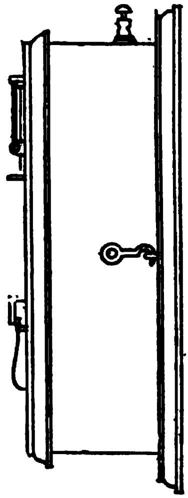


FIG. 192.

In order to work this system, it is, above all, necessary that the different calls should be entirely independent of another, and that there should be no possibility of a wrong call being made at either station.

The apparatus designed for this purpose by Mr. Rothen, assistant director of the Swiss Telegraphs, is shown in Figs. 191 and 192. The box is placed near the telephone apparatus proper. Below the six terminals, which will be seen on the top, are two annunciators similar in every respect to those described in § 152. Beneath the two annunciators is a disc with a pointer, which can occupy three different positions—D, I, and II.

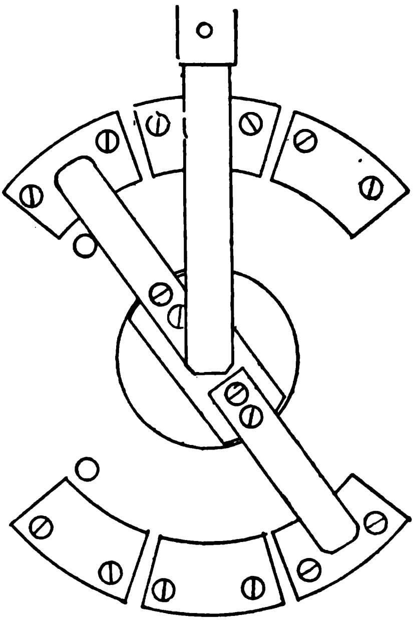


FIG. 193.

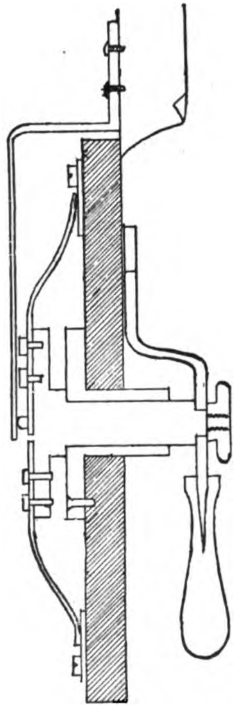


FIG. 194.

When the pointer is placed vertically on I, the central station can call the intermediate station, and *vice versâ* If in this position the distant station calls the intermediate station, the annunciator on the right falls, and rings a special bell. The intermediate station, by moving the pointer to II, reverses the connection, and enters into communication with the distant station. Now, if the central station calls, it is again the annunciator on the right which drops, and the special call bell rings. The operations at the intermediate station are, therefore, very simple. If the call bell of the telephone apparatus rings, the call is treated like any ordinary one from the central station; if, on the other hand, the annunciator on the right drops, and the special call bell rings, the pointer is moved to that one of the two positions I and II which it had not formerly occupied, whatever may have been its preliminary position.

If the distant station wishes to be placed in direct communication with the central station, the intermediate station places the pointer to D, and this completely cuts out the apparatus of the intermediate station, with the exception of the annunciator on the left, which is made to drop by a current sent at the conclusion of the conversation.

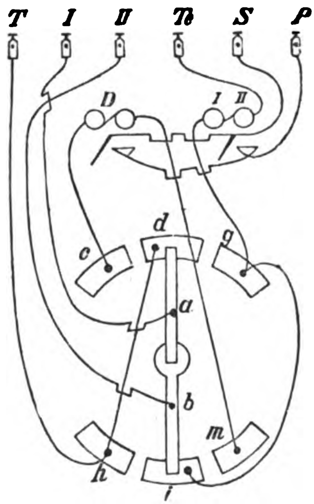


FIG. 195.

Fig. 193 gives a view of the back of the switch, and Fig. 194 a cross section.

Fig. 195 is a diagram showing all the internal connections of the apparatus. The pointer is behind the disc, in communication with two contact springs, *a* and *b*, insulated from one another. These springs slide over six segments—*c*, *d*, *g*, *h*, *i* and *m*—in such order that, if the spring *a* touches *c*, *d* or *g*, the spring *b* touches *m*, *i* or *h*. D and I, II are the two annunciators, below which are shown the springs and contact points which close the local circuit of the call bell, which circuit is completed through the terminals S

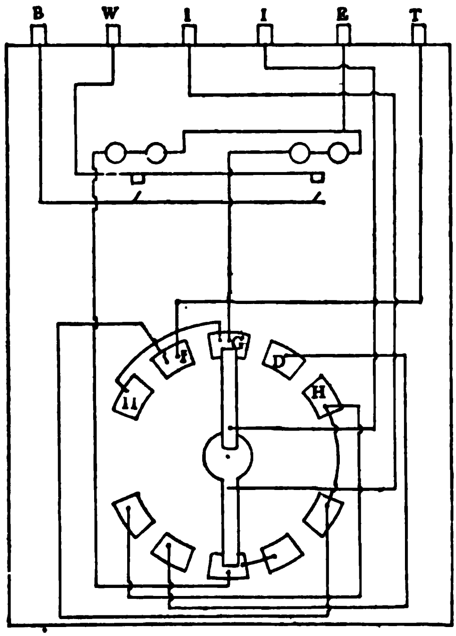


FIG. 196.

and P. Supposing the pointer has the position indicated in the sketch. A current entering through terminal I passes through *a*, *d*, *h*, to terminal T, and thence goes to the telephone apparatus ; and a current entering through terminal II passes through *b*, *i*, *g*, the electro-magnet I II, and thence through terminal T*e* to earth. By moving the two springs *a* and *b* to the segments *g* and *h*, the connections are reversed, as will easily be seen by reference to the sketch. When the pointer is moved to the position *c m*, the current entering through I passes through *a*, *c*, the electro-magnet D, and thence through *m* and *b*, to line II. The annunciator disc at the intermediate station must immediately after dropping be replaced in its original position, for the bell continues ringing as long as the disc is down.

156. A slight modification of the arrangement given above permits the employment of a magneto alternating current call bell, which no longer requires a battery,

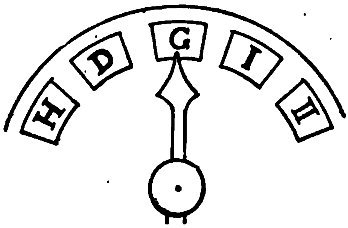


FIG. 197.

and rings only during the time of turning the winch-handle at the calling station.

If it is desired that the intermediate station shall be able to listen to the conversation of the distant and the central station, a five-way switch is used, a diagram of whose connections is given in Fig. 196, and a sketch of part of the disc and the pointer in Fig. 197.

SUB-EXCHANGES.

157. Sometimes a subscriber of the central station wishes to correspond from his office directly in various directions. This would be the case with a tradesman

having several branches in the same town, and wishing to connect his head office with the central station and with all the branches.

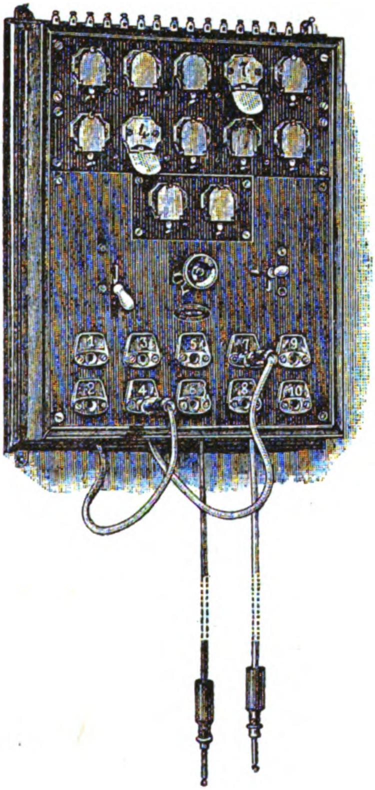


FIG. 198.

The head office in this case would become a sort of secondary central station, whence the wires radiate in different directions. The accessory apparatus then takes the form of a switchboard, having as many numbers as there are outgoing wires.

Fig. 198 gives a perspective of an apparatus intended for the connection of ten stations with an intermediate station. On the top of the board are fifteen terminals, of which one leads to the apparatus of the intermediate station, another to the spring with which the automatic switch is in contact when the receiver is suspended, a third to earth, two to the call-bell and the local battery, and the ten remaining ones to the ten telephone stations communicating with the intermediate one. On the board are ten annunciator drops in two rows of five, and beneath these two clearing-out drops for the end of conversation. Then come three switches on the same horizontal line. The centre switch, with a large button, has three positions: the left, the right, and the vertical. The two switches on either side have two positions each: a horizontal and an oblique one. Beneath these switches are ten plugholes corresponding to the ten annunciator drops. Two pairs of cords suspended from the lower end of the board and terminating in plugs complete the arrangement. When all is at rest, the annunciators are up, the side switches are in their horizontal position, the central switch is to right or left, the four cords hanging down. The position represented in Fig. 198 indicates the establishment of communication between the stations Nos. 4 and 7, at the same time enabling the intermediate to ascertain that the two stations can converse together.

158. If a network is so large that the number of wires can no longer be accommodated in one central station, 500 to 800 wires are laid underground to a convenient

spot at some distance from the central station, and thence radiate from a sort of tower (called a dummy station) to the neighbourhood. For the connection of these telephone towers with the central station, so-called anti-induction cables are used.

Telegrams and Messages transmitted by Telephone.

159. Upon making a written application to the central telephone station, or the central telegraph office, every subscriber may be authorised to use his apparatus for sending and receiving his telegrams. The central telegraph office in this case opens an account with the subscriber, which he is obliged to settle every month.

An additional charge of ten centimes (one penny) is made to the customary charge for each telegram so sent or received.

Arriving telegrams transmitted by telephone are still subsequently delivered by messenger if the subscriber lives within the radius for free delivery (one kilometre). If he is outside this radius they are posted, unless the subscriber desires their delivery by special messenger.

Subscribers can also send messages to non-subscribers. The charge is ten centimes fixed, plus one centime per word, the whole sum always to be made up to a multiple of five. If the messenger has to deliver the message within the radius, but outside the hours of delivery, one franc extra is charged.

Non-subscribers can send messages to subscribers at the same charge (ten centimes fixed and one centime per word) by sending their messages in writing to the central telegraph office.

Telegrams and messages transmitted by telephone must be either in French or German ; they must be dictated slowly, and with a pause between every three or four words.

Rental Charges.

The annual subscription for subscribers of the same network is 150 francs (£6), an amount which compares favourably with the £20 charged by the United Telephone Company in London, and the £12 charged by the Lancashire and Cheshire Company, and is, in fact, lower than the subscription of nearly all the telephone companies both in Europe and all over the globe. For Government and parochial buildings, as well as for benevolent institutions, this amount is reduced to 100 francs (£4).

For branch connections the subscription is 170 francs for the first branch, and 100 francs for each additional branch in connection with the central office. A further reduction of 20 francs for each branch is made if the distance between the individual branches does not exceed 500 metres.

Public Telephone Stations. Charges.

I.—*Within the System.*

(*a*). Conversations :—

A subscriber speaking with another subscriber pays five centimes for each five minutes, or fraction of five minutes, conversation.

A non-subscriber talking with a subscriber pays ten centimes for five minutes, or fraction of five minutes, conversation.

(*b*). Messages (telegrams) :—

A message pays twenty centimes fixed, and one centime per word.

II.—*Between different Systems.*

Only subscribers are allowed to speak. Thirty centimes are charged for a conversation of five minutes, or fraction of five minutes.

Testing Batteries.

160. In order to facilitate the testing of the batteries, which are often the cause of imperfect working of the apparatus, M. Rothen has constructed a special so-called

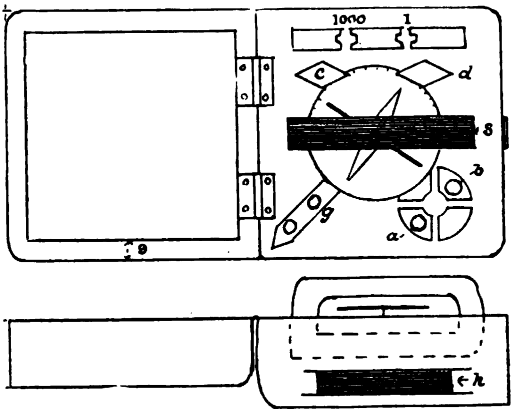


FIG. 199.

battery galvanometer, represented in projection in Fig. 199, and in perspective in Fig. 200. The needle is in the centre of a flat helix *a* (Fig. 200), composed of two kinds of wire: the one very thick, practically without resistance, which passes once round the needle; and the other a fine wire, having 1,000 convolutions. The wires coming from the battery element to be tested are fixed to the terminals *b* and *c*. The plug *d* acts as a pole-changer; that is to say, that in one position of the plug the current passes through the helix in one direction, and, if the plug is moved through an angle of 90°, it passes in the opposite direction. The other plug *e* serves to close

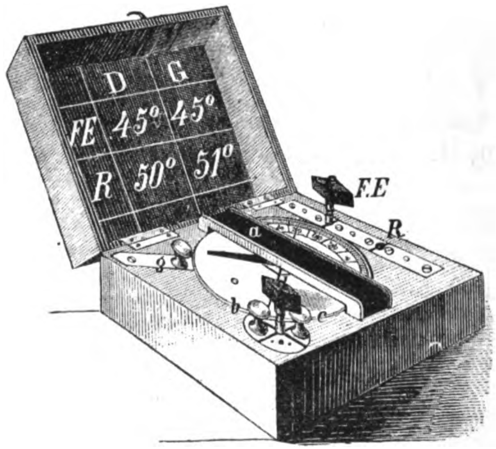


FIG. 200.

the circuit. By inserting it into the hole marked F.E the electro-motive force of the element is measured, whilst by inserting it into R, its internal resistance is determined. These methods are based on the following arrangement: At F.E the 1,000 convolutions are placed in circuit; but on simply allowing the current to traverse these 1,000 convolutions, the needle would be suddenly deflected to nearly 90°. In order to avoid this sudden deflection, a supplementary high resistance coil is added to the galvanometer, shown at *h* in Fig. 199, and placed parallel to the plane of oscillation of the needle. This is connected with the coil of 1,000 convolutions in such a way that every current which passes through the latter must also traverse the auxiliary coil, whose resistance is therefore added to it. The auxiliary coil receives a resistance of such magnitude that the current of a good Leclanché element, passing through it and the coil of 1,000 convolutions, deflects the galvanometer needle by about 45°. In taking this measurement the internal resistance of the element can be neglected in view of the resistance of the galvanometer. Each battery galvanometer is carefully calibrated before being used, and the result is marked inside the cover of the case. In the same way the deflections are determined by inserting the plug in the hole marked R, and employing a normal element, whose internal resistance is ·75 ohm; this figure, too, is marked inside the cover. To test an element with a galvanometer thus calibrated, the plug is first inserted at R. If the deflection reaches, more or less, the normals for R, inscribed on the cover, everything is in order; the E.M.F. and resistance are normal; but when the deflection is sensibly weaker the plug is inserted at F.E. If, under this new condition, the deflection reaches the normals, the E.M.F. is good, but the internal resistance is too high; if, on the contrary, the deflection is too feeble, it is the E.M.F. which is wrong.

The following Table will give some idea of the present extent of telephonic communication in Switzerland:—

SWISS TELEPHONE NETWORKS IN EXISTENCE ON THE 30TH SEPTEMBER, 1886.

Arranged according to the number of Subscribers.

Groups of Networks.	Networks.	Central Stations.	Subscribers' Stations.	Conversations in August.		Lines.	Wires.
				Local.	With other Nets.	Mètres.	Mètres.
Lake of Geneva ...	8	6	2,021	267,869	7,959	487,177	2,770,180
Zurich	14	15	1,419	161,627	8,536	407,392	1,625,220
Berne	8	14	890	56,159	3,790	275,368	837,123
Bâle	2	9	731	65,082	672	171,478	796,550
St. Gall	4	6	394	42,816	2,111	168,025	609,237
Independent Networks	3	—	123	3,095	—	62,638	195,127
Total ...	39	50	5,578	596,728	23,068	1,572,078	6,833,437

A number of new lines have been added since, amongst which are Colombin and Burgdorf, belonging to the Berne group; Auran, belonging to Zurich; Glarus, an independent line, and several others. The Van Rysselberghe system, which will be described in a subsequent chapter, has been adopted between Geneva, Nyoa, Morges, Lausanne, and Vevey, between Zurich and Männedorf, and lately also between Bâle and Zurich.

CHAPTER XVIII.

TELEPHONE EXCHANGES.

(a).—*THE LAW SYSTEM.*

161. THIS system, invented by Mr. Frank Shaw, engineer of the Law Telegraph Co., of New York,

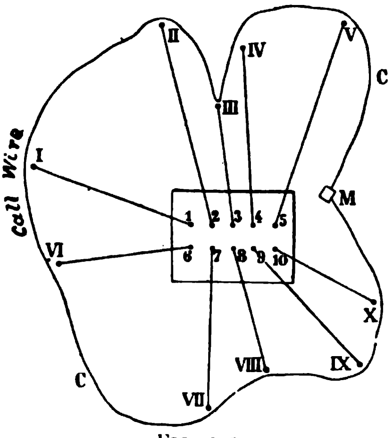


FIG. 201.

operates exchange systems in New York and Brooklyn, and its central offices are connected by trunk wires with those of the Metropolitan Telephone and Telegraph Co., thus enabling the subscribers of the two companies to inter-communicate.

The telephone instruments used by the Law Telegraph Co. are the Blake transmitter and the Bell receiver.

As in all other systems used in New York, each subscriber is connected with the central office by a single wire.

At the central office their lines end in flexible cords, provided with metallic pegs, which are arranged in the centre of the communication table.

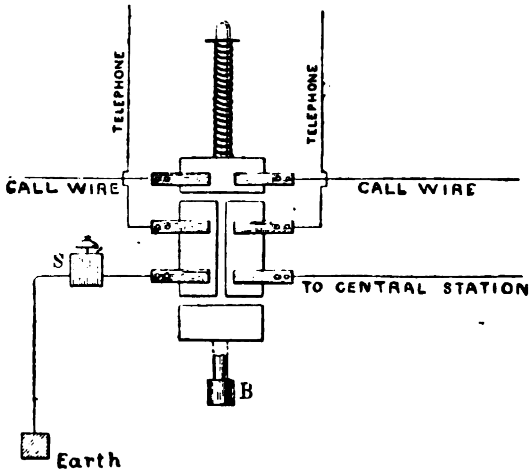


FIG 202.

The characteristic part of this system consists in the employment of a special wire C, Fig. 201 (known as the "calling wire"), which joins a certain number of subscribers (generally one hundred and thirty), and, after having passed through the apparatus placed in the network, returns to the central office telephone, M, where an operator is always listening.

When one of the subscribers wishes to call, he introduces his telephone on the wire C, and then he can correspond directly with the exchange telephone M, whose receiver is always held to the ear of the operator.

It is understood that the subscriber, in order to call has only to give his number and that of the subscriber with whom he wants to speak.

The operator then takes the peg of the required number, presses it against a plate connected with the battery and thus rings the bell of the called subscriber.

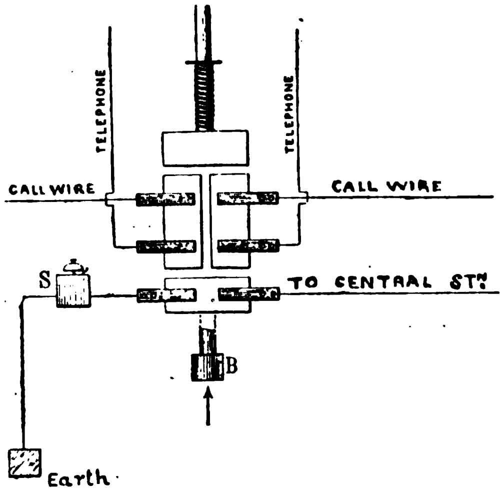


FIG. 203.

He then inserts the two pegs into a metallic bar, and the two subscribers are in communication.

When the conversation is finished, the two subscribers put themselves again on the calling wire C, and request the operator to break the connection. It will be seen that in this system the indicators are altogether omitted. The operator has a telephone fixed to his ear by a spring surrounding his head, and he constantly listens to the directions given on the calling wire. His two hands are free to make switch-connections. One operator generally attends to from one hundred to one hundred and thirty subscribers. Of course, to render the service efficient, the operator must be a trained person, who does not confound the numerous and simultaneous calls.

Another characteristic feature of this exchange is a special switch, which serves for putting the telephone on the calling wire.

The connections of this switch are shown in Figs. 202 and 203.

Fig. 202 gives the connections in the normal position. The wire coming from the exchange passes through the switch of the telephone (which short-circuits the telephone), the call bell, and then goes to earth. A current sent from the exchange, therefore, rings the bell. The calling wire passes directly through the station.

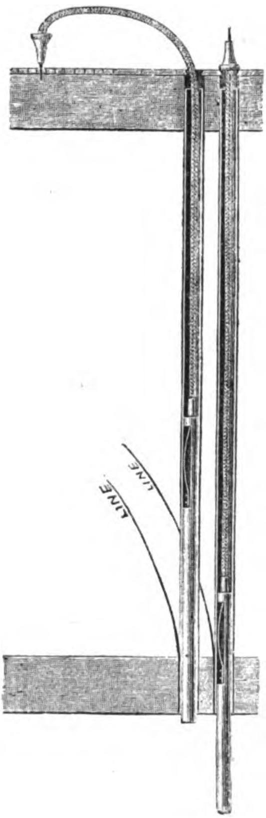


FIG. 204.

Fig. 203 represents the position of the switch when the subscriber wishes to call the exchange.

In this case the subscriber's line is out of circuit, and the telephone is put on the calling wire.

As we have mentioned, the subscribers' lines end at the central office in a flexible cord, terminating in a metallic peg. In the centre of the communication table copper tubes (Fig. 204) are fixed, which are insulated from one another. The line wires are joined to the mass of these tubes, and the cord, provided with a counter-weight, is placed entirely inside the tube, contact being made by a spring rubbing against the side of the tube.

Lately the Law Telephone Co. have introduced switches on the "multiple" system, by which an operator can put one subscriber through to any other without having recourse to any intermediary. These are similar in principle to the Western Electric Co.'s multiple switchboard, which will be subsequently described.

(*b*).—*THE MANN SYSTEM.**

162. This system is a modification of the Law system, and has been successfully worked for the last five years in the Dundee district by the National Telephone Co. It has just been shown that in the Law system each subscriber, in addition to having a direct wire to the exchange, has the power, by pushing a switch, to loop his instrument into a common wire which, starting from the exchange, goes from office to office, and finally is brought back to the exchange, after making connection with several subscribers' instruments. But this long loop wire into which the subscribers have to switch their instruments is found- in practice, to be liable to interruptions from various

* "Engineering," 25th March, 1887.

causes; and as no other means for corresponding with the exchange is provided, its failure necessitates a suspension of service, which is sometimes of many hours' duration. The breaking of the calling wire, or a disconnection of any one of the numerous instruments through which it passes, breaks down the whole system on that calling wire.

The Dundee system is free from these objections,

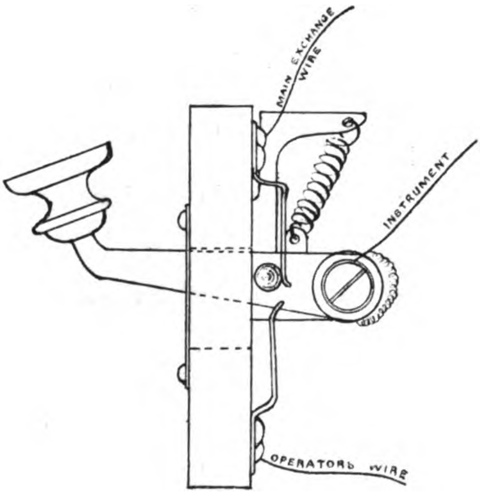


FIG. 205.

while all the advantages of the "Law" method are retained. Each subscriber is on the calling wire; and he is, in addition, provided with an ordinary shutter indicator, which is intended for use only in the event of the operator's wire failing. The calling wire does not make the circuit of all the subscribers' offices, but starts from the exchange, as nearly as possible, mid-way amongst the group of, say, from fifty to ninety offices which it is intended to serve. It is not led back to the exchange, but terminates abruptly at any convenient point at any distance from the exchange. Into each subscriber's office, to the right and left of this calling wire, a branch or spur is taken which is connected to the bottom contact of a key switch attached to the subscriber's instrument.

This switch is represented in Fig. 205. The lever of the key is connected permanently to earth through the instrument, and the upper contact to the subscriber's main line to the exchange. The lever is kept against the upper contact by means of a spiral spring, so that the instrument is normally connected to the main exchange wire.

The ordinary working is as in the Law system. At the exchange an operator is allotted to each group of from fifty to ninety subscribers, who listens continually at a telephone joined to the operator's or calling wire of that group. It follows that the subscriber, on pressing his key, finds himself at once in communication with the operator, and has only, without any preliminary signal or call, to mention his own number and that of the person whom he wants. For instance, No. 25 desiring to speak to No. 600, would press his key and say: "25 to 600." The operator acknowledges the order by a word, and immediately makes the connection. No. 25 then allows his key to rise, turns the crank of his magneto, and rings the bell of No. 600. Supposing that no immediate response is obtained, he can, by again pressing his key, inquire of the operator if the connection has been properly made, or ask any other question that may be thought necessary. After finishing his conversation, No. 25 presses his key again, and says to the operator:

"25 off;" or, if he wants another subscriber: "25 to 92." In the first case, the operator simply removes the cord connecting 25 to 600; in the second, he takes one end of the cord and transfers it to 92. It is frequently the case that two, three, or even four subscribers press their keys simultaneously, but the necessary communication to the operator, consisting, as it generally does, of only two or three words, occupies such a very short space

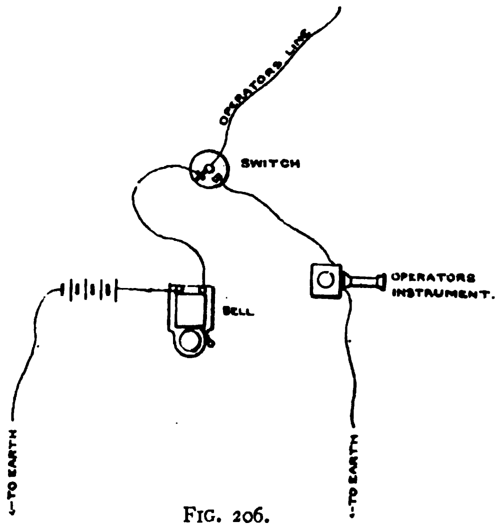


FIG. 206.

of time that no trouble is experienced, the subscribers having got into the habit of waiting a few seconds if they find, on pressing the key, that somebody else is speaking.

163. If an accident has happened to the calling wire, the subscriber discovers the fact immediately, for, on pressing the key, he does not obtain any reply from the exchange. In such a case, there being an indicator on his own main line at the exchange, he can signal on that

by means of his magneto, and the service is conducted on the ordinary plan until the fault has been rectified.

The operator ceases to listen continually after 9.30 p.m., when the calls from the subscribers become less frequent. After that hour, until 8 a.m., a battery and a bell are switched into each calling line at the exchange, as shown in Fig. 206, so that the pressing of any subscriber's key

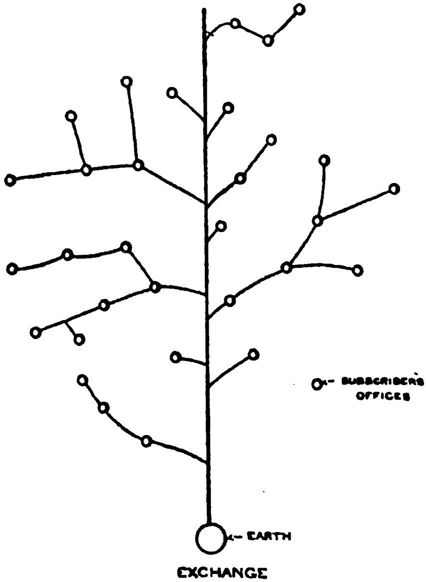


FIG. 207.

at once "earths" the line and causes the bell to ring. So long as none of the keys are pressed the operator's line is insulated from the earth at every point except at the exchange, so that no current flows until a key is depressed.

In Figs. 207 and 208 there is a representation of a group of subscribers' offices (represented by small circles) connected on the Mann and the Law systems respectively.

These do not show the direct main line to the exchange which each subscriber has in practice, but only the calling wires. On comparing the two it will be readily seen that, whereas, on the Law system a fault at any office, or on the calling wire itself, breaks down the whole group, under the Mann system a fault at one office may break down only that office, or that and a few others ; and even

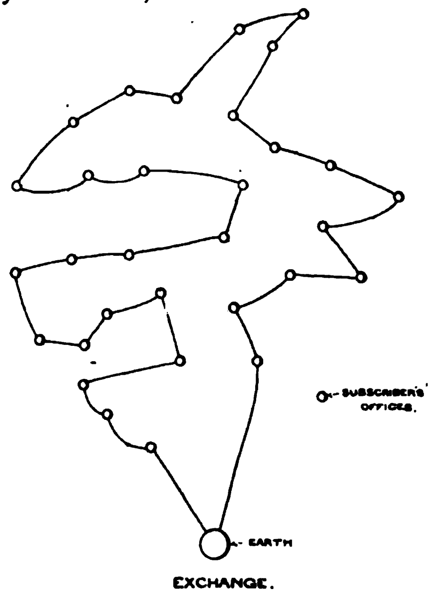


FIG. 208.

a fault on the main calling wire will break down only part of the group.

Experience proves that the indicators which have hitherto been inserted in every subscriber's line, are not really necessary for reliable working, for, since the system was first introduced at Dundee in 1882, it has never been found necessary to make use of them. Their removal leads also to the removal of the batteries for working them at the subscribers' offices, and so a considerable reduction in the cost of installation and of maintenance is the result.

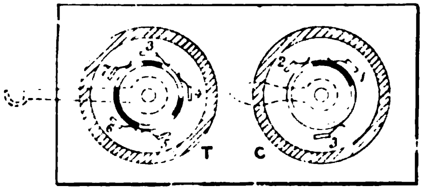


FIG. 209.

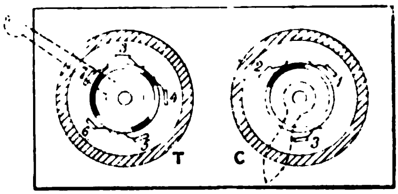


FIG. 210.

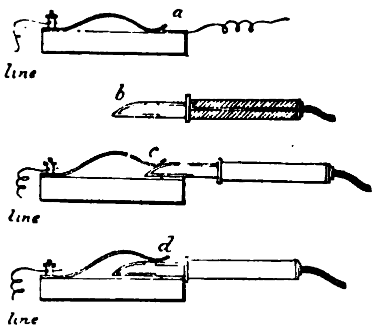


FIG. 211.

164. The switches now used at the subscribers' instruments are the design of Mr. Miller, of the National Telephone Company's Exchange at Dundee. They are shown in Figs. 209 and 210.

The right-hand switch, C, is held in its normal position (Fig. 209) by a spring, and the left-hand switch, T, is normally held in position by the weight of the telephone receiver when not in use. The second positions are shown in Fig. 210. In its normal position C connects the instruments to the subscriber's line, and when it is turned to the position shown in Fig. 210 the subscriber's instruments are connected to the circuit wire. The switch T simply places the calling or the speaking parts in the circuit in the usual way.

At the exchange, a strip of brass is placed just clear of the springs, in front of the rows of switch holes, as shown at *a*, Fig. 211. All these strips are connected to a magneto-generator, the other side of which is joined to earth, and which is kept constantly working by means of a small turbine. Each of the pegs for putting the subscribers into communication is tipped with a piece of brass insulated from the connection plate of the peg (*b*, Fig. 211). If, now, the peg be partly inserted, as shown at *c*, the generator will send a current to the line and so ring the subscriber's bell, and then when the peg is pushed home, as at *d*, the usual connection for putting through is made.

The whole operation of obtaining communication is effected as follows:—Subscriber A places himself on the circuit wire by holding switch C in the position shown in Fig. 210, and then, lifting off his telephone receiver, simply says, "A through to B." By releasing the lever of switch C, the instrument is again in the circuit of his own line. In the meantime the operator at the exchange has inserted one of a pair of pegs in A's switch-hole, and the other peg in B's switch-hole pausing slightly in the latter case when the peg is in position *c* (Fig. 211). B is thus called, and on removing his telephone receiver finds himself in communication with A. If B does not respond, A has only to turn his calling switch C and request the operator to give B another call, which is done by partly removing the peg, pushing it home again to restore communication. At the conclusion of the conversation, A again turns his calling switch and gives "A and B off."

(*c*.)—*THE GILLILAND SYSTEM.*

165. The Gilliland standard switchboard, which is

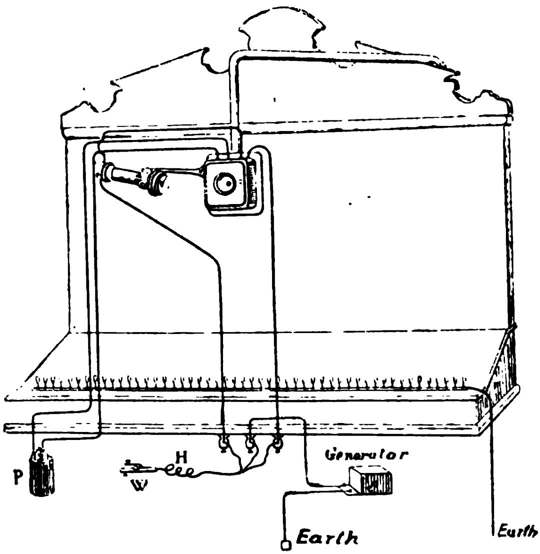


FIG. 212.

shown in diagram by Fig. 212 and in general view by Fig. 213, is extensively used in America.

The crimped strips (Fig. 214), extending from the front to the back in groups of ten, are line strips. Those

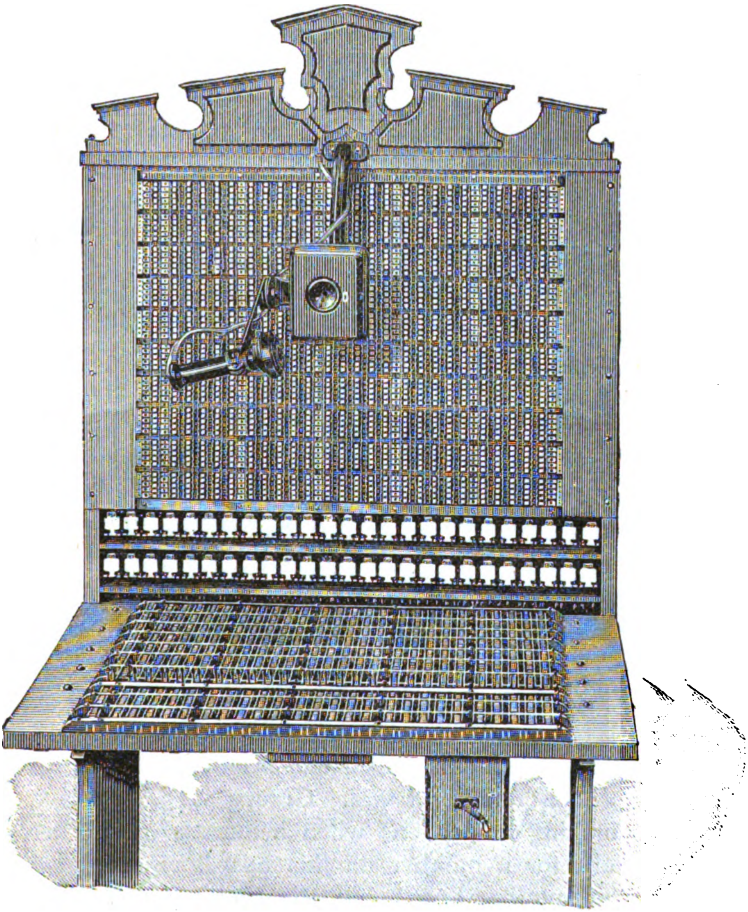


FIG. 213.

running parallel with the front in groups of five are connecting loops. Loop strip B is used to earth all lines. Loop strip C is connected with the generator. Loop strip D is used for plugging into the telephone strip. Line strip L is connected with the telephone. Group E is for making connections which originate and end on the board. Plugs H and I show Nos. 4 and 7 as connected. Group F is for making connections which originate on this board and end on another; Plug G

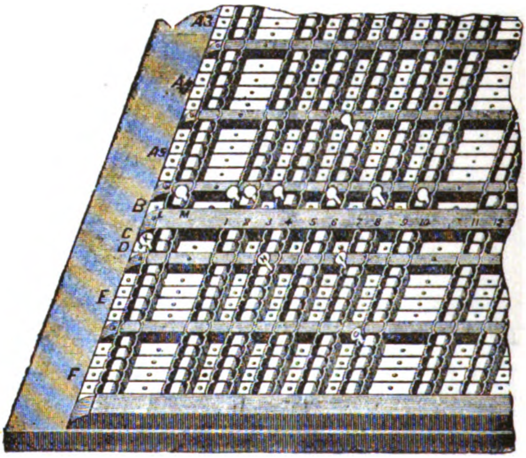


FIG. 214.

showing No. 9 as having called and been connected with a number on another board. Groups A, 3, 4, and 5, are for making connections when a number on another board calls for a number on this board. Each group represents another board, but the connections of the board are so run that, should more than five connecting loops be needed for one table, loops may be borrowed from another group. Plug N shows a call originally on another board connected with No. 5. The operator can always listen by plugging in on L at any loop desired. When not in use, all lines should be earthed by plugging them on ground strip B.

Fig. 215 shows the Gilliland switchboard for five lines,

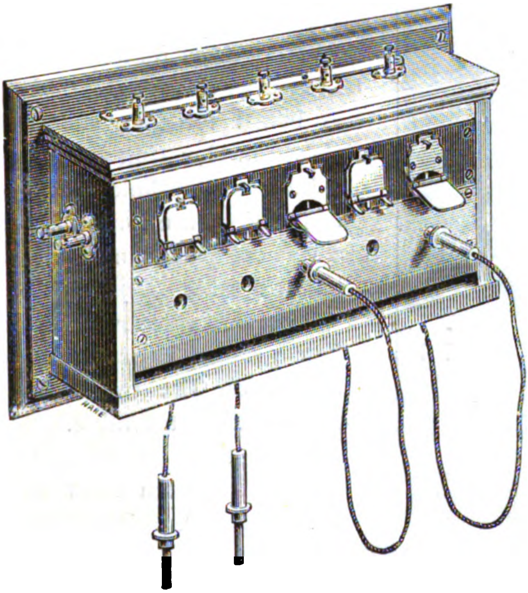


FIG. 215.

constituting a complete telephone exchange for a small number of wires. It it designed for factories, charitable institutions, railroad offices, and the club system of small towns and villages. The operation of the board consists simply in inserting plugs into the switch-holes of those desiring to be connected.

(*d.*)—*THE WILLIAMS' SPRING SWITCHBOARD.*

166. Mr. Ch. Williams, of Boston, Mass., was one of the first electricians who devoted themselves to the installation of central offices, and his switchboard is extensively used in America.

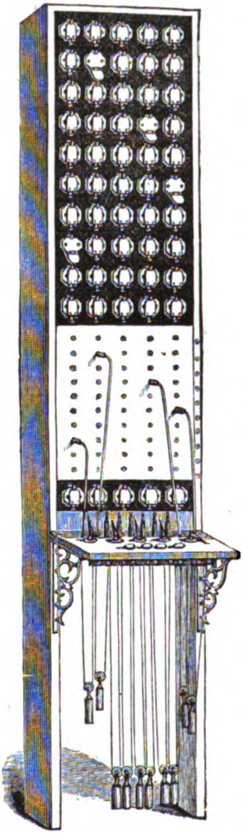


FIG. 216.

In principle, the Williams' board does not differ materially from that known as the *Swiss Commutator.* A board for fifty subscribers is shown in elevation in Fig. 216.

The switch-holes for making connections are arranged partly on a vertical panel and partly on an inclined table.

They are, moreover, divided into four groups, indicated by capital letters on the two sides of the panel and of the table.

The fifty annunciators are arranged in ten rows above the vertical panel. The annunciators themselves are constructed in the same way as those of the Swiss system.

The Blake transmitter and the telephone receiver employed by the operator are fastened to a lever, which is arranged in such a manner that the operator can handle them easily.

Fig. 217 shows a section through the board. It will be seen that the vertical bars of the Swiss board are replaced by a series of curved springs, *d*, touching each other, and thus forming, as it were, one single conductor. The board has received its name "spring switchboard" from the use of these springs.

The subscriber's line L enters by means of wire No. 1 to the spring R, and thence (supposing the plug W to

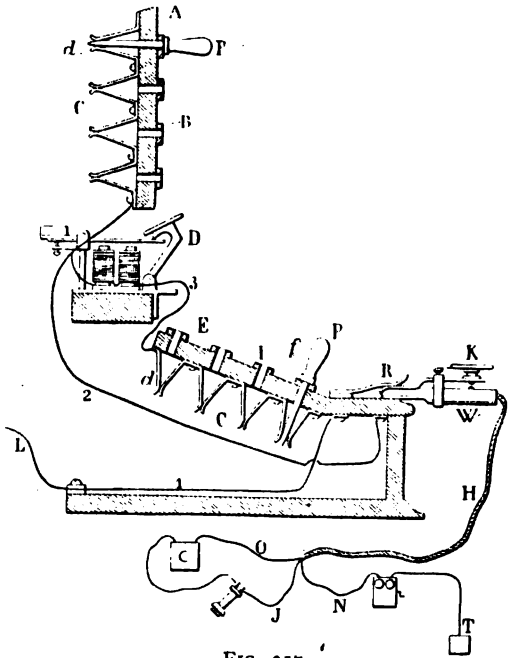


FIG. 217.

be removed) into the electro-magnet of the annunciator D; from this latter it passes on to the spring *d*, and finally through the plug P to the horizontal bar *f*, which is connected to earth.

The springs of the vertical panel B are also connected to the same line.

As will be seen in the sketch, all the pegs, P, are arranged in a state of rest on a vertical bar, which communicates with earth.

As soon as a subscriber has called, and the annunciator bearing his number has dropped, the special plug W is introduced into the corresponding spring-jack R, and the receiver and transmitter of the operator are thereby introduced into circuit.

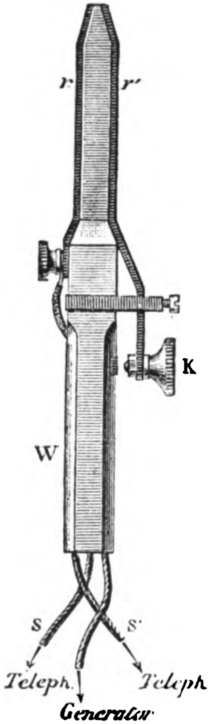


FIG. 218.

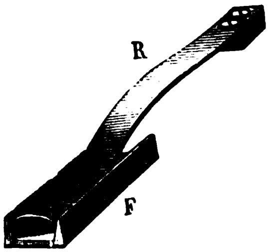


FIG. 219.

This plug and the spring-jack are represented in Figs. 218 and 219. On a piece of vulcanised fibre are fixed two metallic strips, $r\ r^1$ insulated from one another, but communicating with the two wires of the operator's telephone. When this key is inserted into spring-jack R, between the spring and the support F, the subscriber's apparatus is placed in circuit, and he can now announce the number he wishes to talk to. When he has done this, the plug W is inserted into the corresponding spring-jack, and the key K is pressed, which sends the current of the power-generator to line and rings the called subscriber's bell.

As soon as he has answered, the two subscribers are placed in communication by inserting the two corresponding plugs on the same horizontal bar.

(*e*).—*NAGLO BROS.' TELEPHONE SYSTEM.**

167. This system has been designed by Messrs. Naglo Bros., of Berlin.

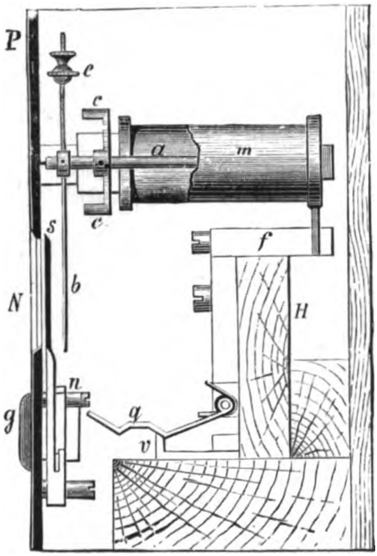


FIG. 220.

It consists of a switchboard with annunciator discs for the central office, and of a peculiar alternating current generator for each subscriber.

Fig. 220 represents a section of a single switch-hole

* "Electrotechnische Zeitschrift," No. 1, 1886.

and an annunciator, and Fig. 221 the general form of the switchboard. On the axis *a*, which is pivotted between two points, the signalling disc *b* is fastened, and

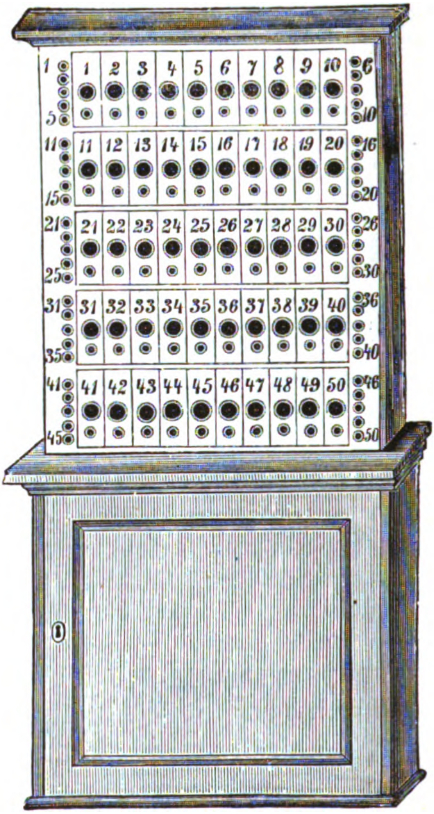


FIG. 221.

behind it the magnet *c*. The axis runs parallel to the cores of the electro-magnet *m m*, which are fastened to the plate P. The magnet *c* can thus approach on both sides the polar pieces of the electro-magnet *m m*.

The signalling disc is balanced by means of a weight *e*, and of a pin *d*, so as to be able to take up position on either side.

In the position, Fig. 222, the disc has been brought by the call current to face the opening N, and it retains

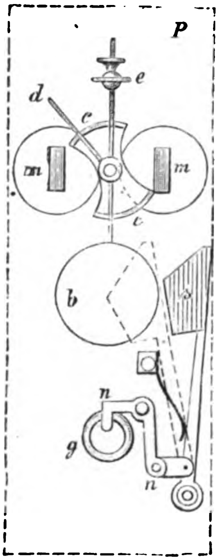


FIG. 222.

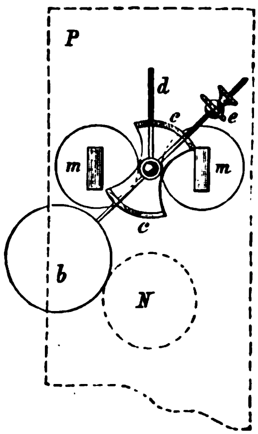


FIG. 223.

that position, being thus rendered visible to the operator.

A current of a contrary direction brings back the disc into position (Fig. 223). In order to render the signals clearly discernible, the disc is white and the background black.

To avoid mistakes or loss of time when several subscribers call at the same time, a contrivance placed behind the plug-hole indicates to the operator the connections already made; as soon as the plug has been inserted into the hole *g* (Figs. 220 and 222), the articulated lever *n* is raised, and a red-coloured signal *s* appears in front of the disc *b* (Fig. 222). On withdrawing the plug the signal *s* disappears again.

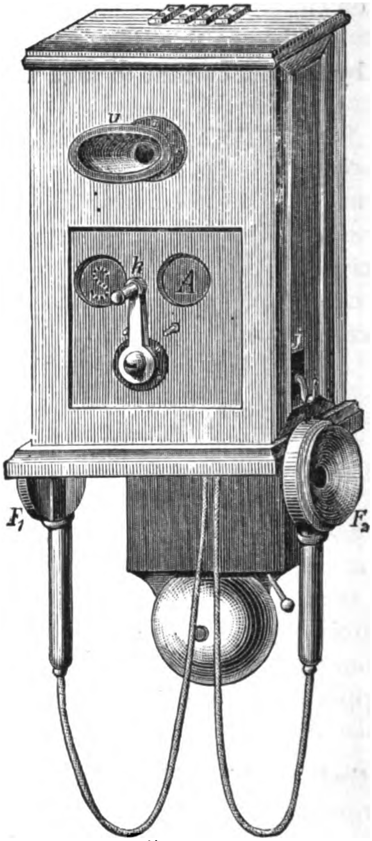


FIG. 224.

The different colours have the following significations:—

Black field: State of rest.

White field: Call.

Red and white fields Connection made.

Red and black field: Disconnect.

The functions of the operator at the central office are therefore restricted to the making of connections.

The repeated fall of the shutters, which is so tiresome in most of the other systems, and which in some cases occurs whenever a subscriber has to call, it may be several times, to the other station, entirely disappears in this system.

The mechanism which is fixed to the front plate can, as in other apparatus, be removed separately for each line, whilst that part of the mechanism which is fixed to the block H remains in place; the communication of the electro-magnet *m m* with the line is made by means of the brass springs *f*. (Fig. 220.)

Fig. 224 shows the subscriber's station; the metallic mouthpiece U opens on the transmitter; the station comprises, besides two receivers, F_1 and F_2, a switch, a call bell, and a lightning arrester.

A call is made by turning the handle *k* to the right; the letter A disappears and S appears; at the central office the white disc appears. When the conversation is ended, *k* is turned in the reverse direction; the letter A becomes again visible, S disappears, whilst the white disc disappears at the central office. The two letters A (*Anruf*, German for *call*) and S (*Schluss*, German for *end*) inform the subscribers whether the signals have been properly made.

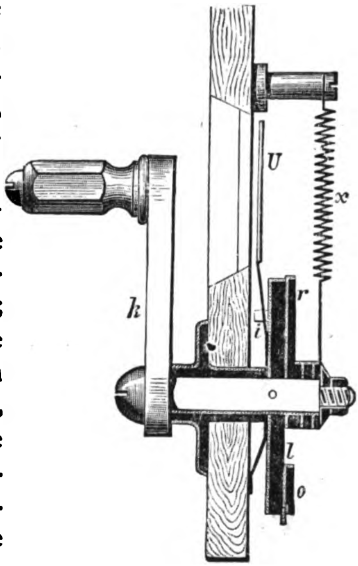


FIG. 225.

The switch is represented in Figs. 225 and 226. The disc *l*, of insulating material, carries two brass plates *r* and *o*, likewise insulated from one another. The springs $f_1 f_1$ are in communication with the negative pole, and

$f_2 f_2$ with the positive pole. If now, for instance, *k* (Fig. 225) is turned to the left, the negative current goes from f_1 to *r*, and thence through h_1 h_2 and *x x*, to line L, and the positive current goes through f_2, *o* and f_3 to E which is connected to earth.

At the same time, f_3 has left the small stud against which it rests, and rubs against the edge of the brass

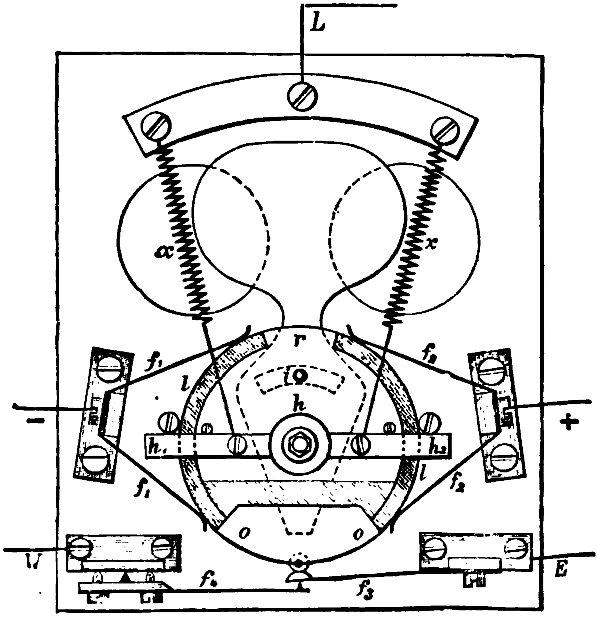


FIG. 226.

plate *o* itself, and this breaks the connection between f_3 and f_4, and therefore between the call bell and earth. The call bell is, therefore, only rung at the called station, since it is interpolated between L and W.

The signalling disc U (Fig. 225) is controlled by the finger *i*, and thus hides the letter A.

The springs *x x* always bring back the switch to its normal position, thus disconnecting the only battery which is required.

(*f*) *THE CHINNOCK SYSTEM.*

168. Of the eleven exchanges operated by the Metropolitan Telephone and Telegraph Company, of New York, five are worked under this system, and one under a modification of it. The extent of its use, therefore, entitles it to notice, but, as it contains no essential principle that has not already been described, a lengthened description is not needed.

The switchboard itself is constructed on the principle of the *Swiss Commutator*, commonly known telegraphically as the *Umschalter Switch*. Running horizontally across the front of the board are strips of brass, about half an inch in width, insulated from each other. There are one hundred of these strips, arranged in pairs. Series of holes are placed in these strips at a distance of ½ inch from centre to centre, and immediately behind these holes, which are arranged in the several strips vertically above each other, are vertical strips of sheet brass, set at such an angle that a metallic pin pushed through one of the holes in front of the board would press against the strip of brass in the rear, and thus establish a metallic connection between one of the horizontal brass strips on the front, and one of the vertical brass strips on the rear of the board.

From this arrrangement it will be seen that each vertical line may be connected with any one of the brass strips upon the front of the board. The wires from the various subscribers are attached to the correspondingly numbered vertical strips on the switchboard.

The manipulation of the switch is very similar to that of the William's switchboard described in § 166.

CHAPTER XIX.

TELEPHONE EXCHANGE MULTIPLE SWITCHES.

THE WESTERN ELECTRIC MULTIPLE SWITCHBOARD.

169. THE multiple switchboard was described by the last American "Telephone Convention" as the nearest approach to a perfect system. It is now being adopted in all large exchanges in the United States and in England.

The connections are made in the same way as in the old exchanges, but they can be made in less time; the operator need not get up from the board before which he is seated, there is no talking, and the distribution of the wires is very clear though complicated.

Fig. 227 represents the principle of a central telephone station. A, B, and C are sections of three switchboards, which receive the wires of the different subscribers. In the diagram three subscribers are indicated for each board, but in practice a multiple switchboard usually contains two hundred in one section. It will be seen that all the wires of all the subscribers pass behind each of the boards, and have a means of making contact in front, and the operator has them all within reach of his hand; so that he can join each of his subscribers with any wire whatsoever, without the assistance of a second operator, and without moving from his place.

Thus, if subscriber No. 2 wishes to speak to No. 8, the operator need not inform board C, which contains No. 8, nor need he go there himself; by placing a plug in the switch-spring he simply joins No. 2 with the

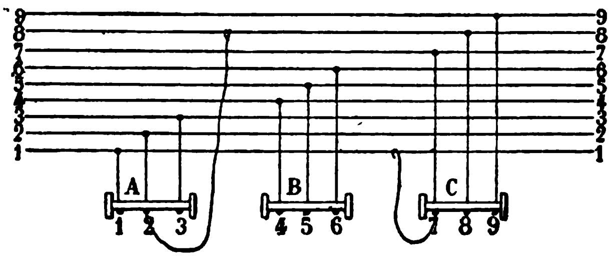


FIG. 227.

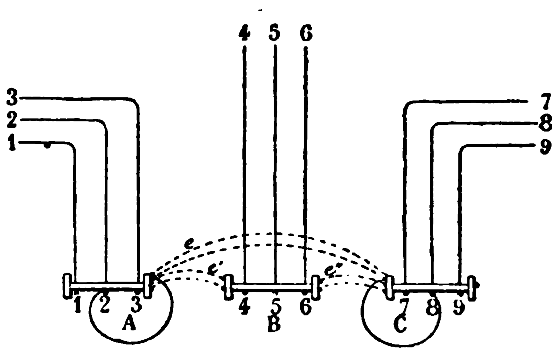


FIG. 228.

wire of No. 8, which is within reach of his hand, by means of a flexible conductor, as indicated in the figure.

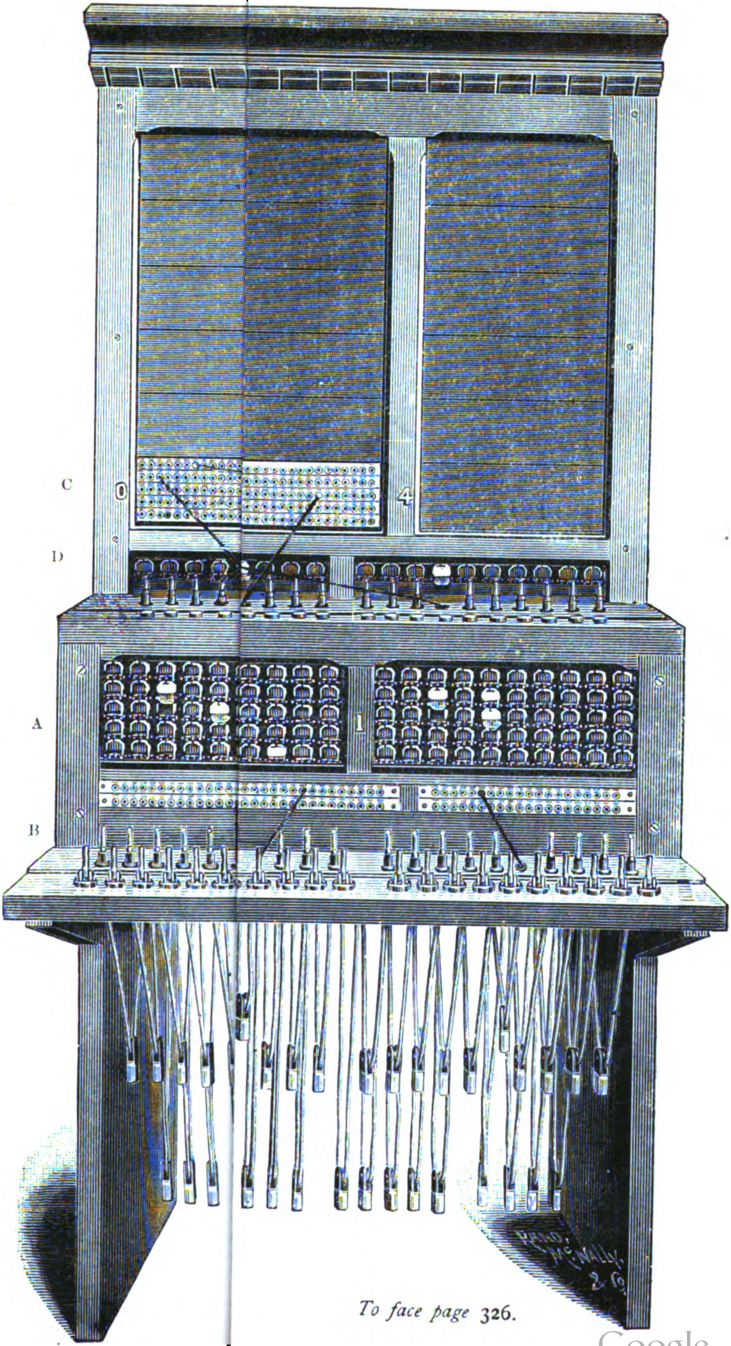
In the same way the operator of switchboard C has made connection between subscribers No. 7 and No. 1.

The difference between this system and that hitherto in general use will be more easily understood by comparing Fig. 227 with Fig. 228, which latter represents a non-multiple telephone exchange, where a certain number of wires are assigned to each board without passing through the others. To make connection between Nos. 2 and 8, No. 2 is joined by a flexible cord to a special wire *e* which leads to board C, and there connection is made by another cord between *e* and 8. A similar operation must be performed for disconnecting the two subscribers.

On examining Fig. 227, the principal difficulty in constructing a multiple switchboard will immediately present itself. Let us suppose that, instead of nine subscribers, as in the diagram, there be several thousand, and that the wire of each one has to pass through each board, and it may easily be imagined what an enormous number of wires will be found behind the board, and how much skill and care are required in the mounting.

170. Fig. 229 represents a multiple switchboard constructed by the Western Electric Company for the town of Milwaukie. Each operator has a similar board in front of him. The two hundred wires of the subscribers to whom he has to attend pass through the annunciators of section A. All the other wires of the entire office communicate each individually with the spring-jacks placed in section C and arranged in hundreds in such order that the operator can easily find the called wire.

In section D are the clearing-out drops, which receive



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the subscriber's signal to disconnect. The plugs for making connection are attached to flexible conductors, and always tend to return to their position of rest by

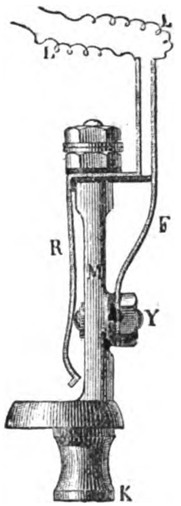
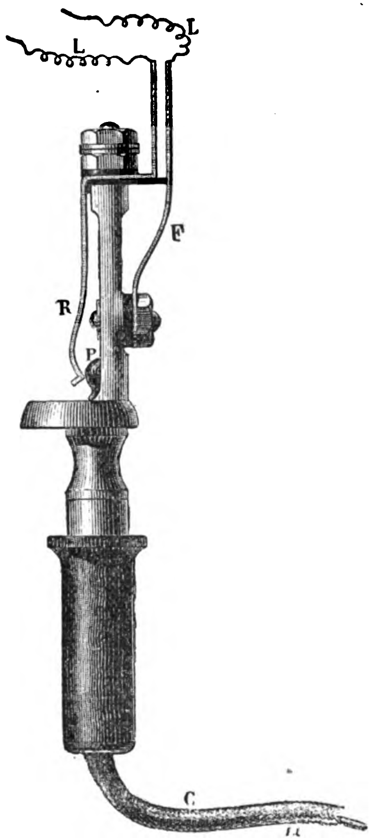


FIG. 230.



means of a pulley and a counterweight. The annunciators are those in common use, and have been previously described. The spring-jacks are slightly modified. The line enters through the spring R (Fig. 230), of phosphor bronze, which is insulated, and rests on a contact screw Y, likewise insulated but communicating with the prolongation of the line by means of strip F. Thus in this position of rest the line passes directly through the spring-jack and goes to the spring-jack carrying the same number at another section of the board; but as soon as a plug is inserted into the switch-hole, as shown, the line passes through the spring R and the metal button P of the plug, into the conducting wire of the flexible cord C. In this position the strip F is completely insulated.

Fig. 231 gives the connections of spring-jacks

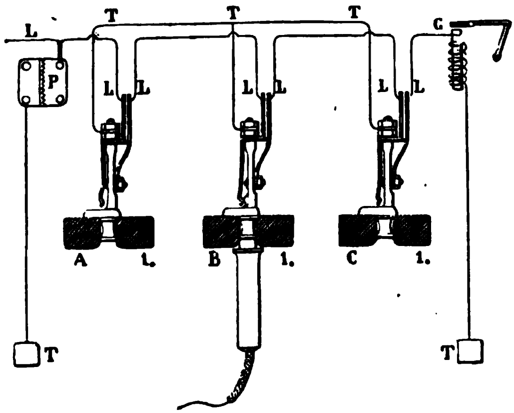


FIG. 231.

carrying the same number, but placed on three distinct sections of board—A, B, C.

The line L, coming from a subscriber, traverses the lightning arrester P and then passes behind all the boards, through all the spring-jacks of the same number, without touching their mass, and finally goes through the electro-magnet G of the annunciator to earth at T. But if we introduce a plug into one of the switch-holes (for instance, in that of board B, as indicated in the figure), the line passes directly into this plug and its flexible cord.

The figure also shows that all the metallic supports of the spring-jacks, carrying the same number on the different boards, are joined together by a wire—T. By this means the operator can ascertain whether the line he wishes to connect on to is occupied or not. If the line is free, the body of the spring-jack, and consequently its external metallic ring, does not communicate with earth, and the operator, by touching the metallic frame

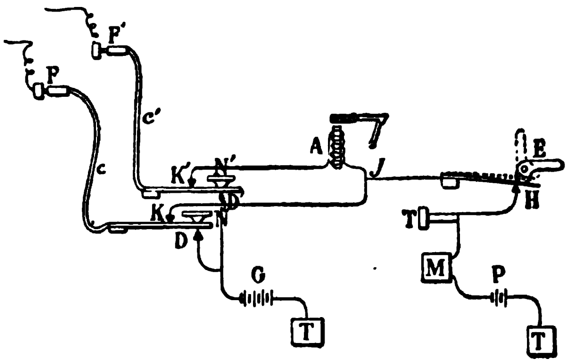


FIG. 232.

of the spring-jack with the plug of his cord, leading to the telephone he holds to his ear, and also leading to the battery, hears no noise, because no current passes. But if the subscriber whom he wants to call is already in conversation with another subscriber, the spring-jack is placed in communication with the subscribers' earths, and the operator hears a noise, which informs him that the line is occupied.

171. In order to explain how connection is made between the subscribers, let us examine Fig. 232, which

gives a diagram of the call keys, the "clearing-out" drops, and the operator's telephone.

Let us suppose subscriber 22 to have called. The shutter of his annunciator at the exchange falls, the operator inserts the plug F into the spring-jack carrying the number 22, turns at the same time the key E, so that there is connection at H, and, holding the telephone T to his ear, asks, by means of the microphone transmitter M, what the subscriber wants. Let us suppose he asks to speak with 750. Then the operator takes the plug F′, which is connected with F, and touches the spring-jack 750, holding the telephone to his ear. If he hears no noise, the line is free, and he inserts the plug, after which he presses on key N′. In this case the current of the generator G (which may be a magneto call or a battery with pole-changer) is sent through the contact D′ into line 750, and the subscriber is called. As soon as the operator lets go the key N′, communication is established between the two subscribers through the annunciator A.

The current path is as follows:—

From subscriber 22, through the cord C, the spring of key N, contact K, annunciator A, contact K′, key N′, cord C′, and line 750.

The telephone T of the operator is still in a shunt at point J, between the line of these two subscribers and earth; but, as soon as the operator hears that the conversation has commenced, he raises the key E, and is then out of circuit.

When the conversation is finished, the subscribers turn the handle of their magneto call-bell, the disc of the annunciator A drops, and the operator removes the plugs F and F′ to their original places.

172. As stated above, one of the greatest difficulties at first experienced in these multiple switchboards consisted in the convenient arrangement of the wires at the back of the board. Fig. 233 represents a section of the board.

All the spring-jacks, S, are arranged in groups of twenty, leaving a space free for the passage of the

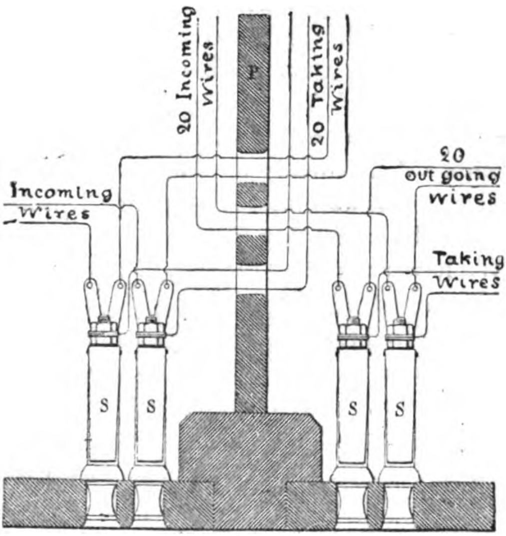


FIG. 233.

cables. There are, besides, perpendicular boards fixed at the back of the switch-board which are perforated with holes, through which the cables pass in a certain definite order. These boards serve at the same time as supports.

In this manner the cables with the wires that go to the spring-jacks are arranged so that they can be raised, in order to get at the spring-jacks and make any repairs, should such become necessary.

It will be seen that the underlying principle of the multiple switchboard, as its name implies, is a multiplication of the connecting points for each subscriber, so that, however many subscribers there may be to an exchange, and however many operators in the switchroom, there is a connecting point for each subscriber within reach of every operator.

Such multiplicity of connecting points would obviously be worse than useless unless the operators had some means of ascertaining whether a required line was or was not engaged. The manner in which the switchboard, as already described, so to speak itself communicates this absolutely indispensable information is an extremely interesting feature.

173. We have referred to the complication in construction, and readers of the foregoing description would hardly be prepared for the extreme simplicity of working which the somewhat complicated construction leads to. An operator, in connecting two subscribers, has to do a minimum of work, and does it all himself. The "engaged" test, for instance, can hardly be looked upon as a separate operation, inasmuch as it consists only of touching the framework of the spring-jack with the plug, which has simply to be thrust home if no click is heard. The simplicity of working enables an operator to attend to a very much larger number of subscribers than in any other system, and the adoption of the multiple board means not only a greatly improved service, but a great saving in operating expenses.

The following are some of the accessories of a switchboard outfit:—

Cross Connecting Board, to enable a subscriber to remain connected to the same switchboard number, if for any reason he may be transferred to another outside line. This will be more fully described in the next chapter.

A detailed description of the *Testing Board* will also be found in the next chapter.

The Lightning Arrester Board consists of hard wood strips, each with forty pairs of springs, one pair for each line.

In addition to this form of lightning arrester, some form of earthing lightning protector may be used with advantage in the tower, or wherever the wires enter from the outside. In every case, however, the greatest caution is to be used regarding the insulation, for the noise attributed to "induction" is generally due to simple leakage.

The Power Generator suffices as source of supply for the calling current for an exchange of any size. If water power is not easily available for the motor, the generator may be mounted in a factory, or other place where power is to be had during the day, the current being led to the exchange by an ordinary line. In this case the generator should be connected to earth through a shunt coil of about 600 ohms resistance, to reduce the induction.

The pole-changer is used as an alternative to the power generator at night, or in case of failure of motive power for the latter. It is less satisfactory than the generator, owing to the induction.

CHAPTER XX.

TELEPHONE EXCHANGE MULTIPLE SWITCHES.

MANCHESTER EXCHANGE SYSTEM.

174. SUCH extensive changes have recently been made in central office working of the telephone in Manchester as to amount to a complete revolution. From the three large centres in which the system was formerly worked the wires have all been concentrated into one large exchange in the Royal Exchange Buildings. The latest and most improved form of the multiple switchboard has been adopted. The whole is provided for in a handsome room 120 feet long, specially adapted to its purposes; so that the combination forms a telephone centre, fully equal, probably, to any in existence in regard to its efficiency.

The switchboards provide accommodation for 4,200 subscribers, but at present they are fitted for only 1,600; one of them, in addition, being set apart, together with some special tables, for the working of the long-distance trunk wires, which form a very important feature in the telephone enterprise of this district, and to the working of which much attention has been paid in the new system.

The boards are arranged end to end down one side of the switch-room, the trunk multiple board having the first position next the test-room. Between the latter and the switch-room, at right angles to the general switch-boards, are arranged the special tables before-mentioned for the working of those wires—long distance, call, office, and multiplex—which require special appliances or methods of working.

175. *Test-board.*—The old form was almost in variably an arrangement of double terminals, to one end of which was brought the leading-in wire from outside, and to the other end the wire to the switch-board. When a test had to be made, one or other terminal was unscrewed, the wire taken off, and one from the testing instrument either twisted with the wire off the terminal or clamped in its place on the terminal, according to which side was to be tested. The disadvantages of this method were many. In the first place, an extra length had to be given to all wires, as sooner or later they were sure to get broken at the ends. This extra length was generally left in the form of a spiral coil, which took up a great space and made it next to impossible to keep the wires neat and tidy. Then, again, loose terminals and broken wires frequently resulted from their being handled so often, and the wires were also liable to be connected to the wrong terminals. With the continual changes going on in the wires of a telephonic exchange owing to removals of the subscribers, etc., the leading-in wires were very soon twisted together in a most untidy tangle, so that attempts to trace or extract one of them always gave rise to great trouble, and to straining, and, perhaps, breaking of the wires in the trough.

To get rid of these faults the test-board shown

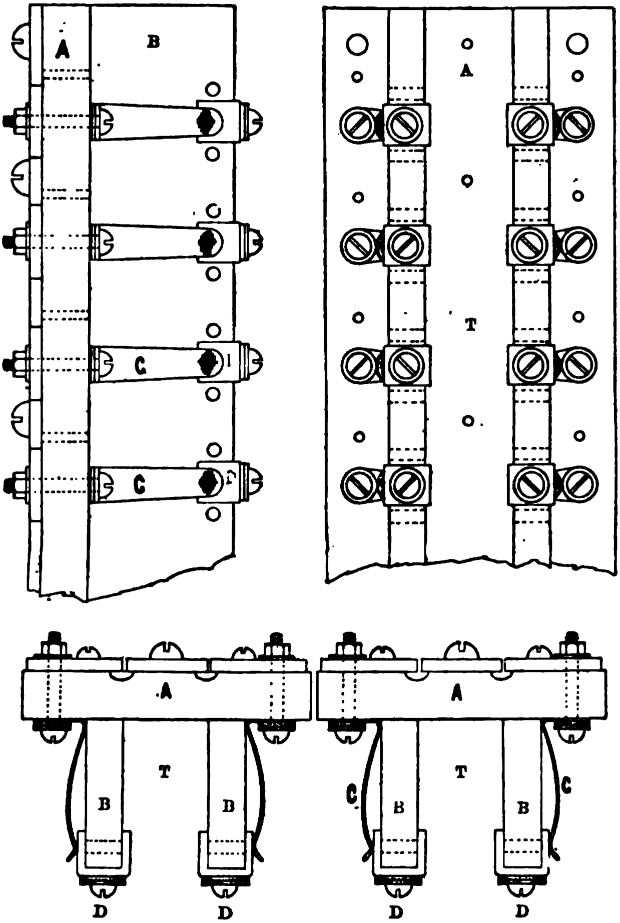


FIG. 234.

in Fig. 234, and the cross-connecting board (Figs. 235

and 236), were devised, by means of which all wires or cables can be run and kept in a perfectly regular and ordinary manner, no matter what changes are made in the subscribers, and by which also all tests can be made without interfering with the wires or terminals to the slightest extent.

176. The *Test-board* is divided into five panels, each of which is again subdivided into ten smaller blocks, part of one of which is shown in the figures. These blocks are made separately, each one complete in itself, with lightning arresters, testing springs, and trough; and when they are fixed side by side other troughs are formed on each side, as shown in the section (Fig. 234). Referring to the figures, A is a piece of ebonite 26 in. long by 3 in. wide and ½ in. thick, on to one face of which are fastened two other blocks of ebonite of same length and 1½ in. wide by ⅜ in. thick; these together form a channel or trough T, through which the wires are led. On the other face of the block A is screwed a wide brass bar, on each side of which, at a distance of 1¼ in. apart, are fixed brass plates, one edge of which is serrated with teeth sharpened by milling; this edge of the plates is adjusted so as to be very near to, but not touching, the centre strip, which is connected to earth. One of the screws which fixes the serrated plate passes through from the front of block A, and the head of it clamps the end of a bent brass spring C. The other extremity of this spring bears against a brass plate provided with screw and washers, and fixed on the edge of the projecting block of ebonite B.

177. *Manner of using Test-board.*—To the testing instruments is attached a wire or flexible cord, at the end

of which is connected a testing plug, which is simply a flat piece of ebonite, to which is fastened on one side a flat piece of brass provided with a binding screw.

By inserting the plug between the end of the spring C and the brass piece D, shown in Fig. 234, so that the brass side comes into contact with the spring, the testing instrument becomes directly connected to the outside line through the binding screw and serrated plate, when any test necessary can be made with the proper instruments. By reversing the plug, the inside wire leading to the cross-connecting and thence to the switchboard is brought into connection, the tests made, and the fault detected, if one exists.

By using a plug with brass pieces on both sides of the flat ebonite, and with a double flexible cord attached, a telephone or other instrument may be inserted directly in the circuit of any line without interfering with the working of it.

178. Part of a *Cross-connecting Board* is shown in Figs. 235 and 236. It is simply a series of flat plates, with screws and washers, fitted on an ebonite plate, to which the cables from the switchboards are brought and soldered in regular numerical order. The screws and washers are used to clamp the ends of the loose wires which complete the connection between the cables on this board and the wires on the test-board.

The manner of joining up the wires on these two boards, in order to keep all regular and tidy, will be readily understood from the diagrams.

All wires from the outside are brought through the main trough, through the slots in the bottom of latter into the troughs T, and are then threaded through

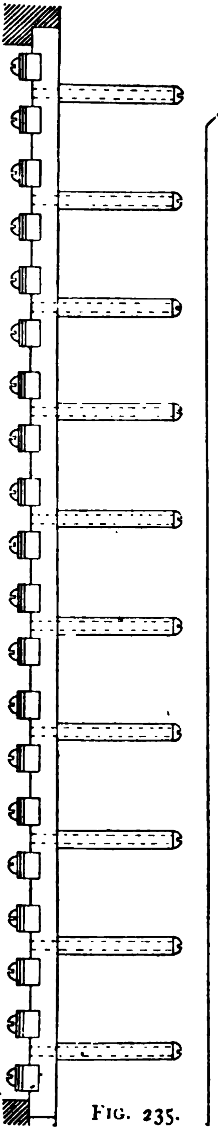


FIG. 235.

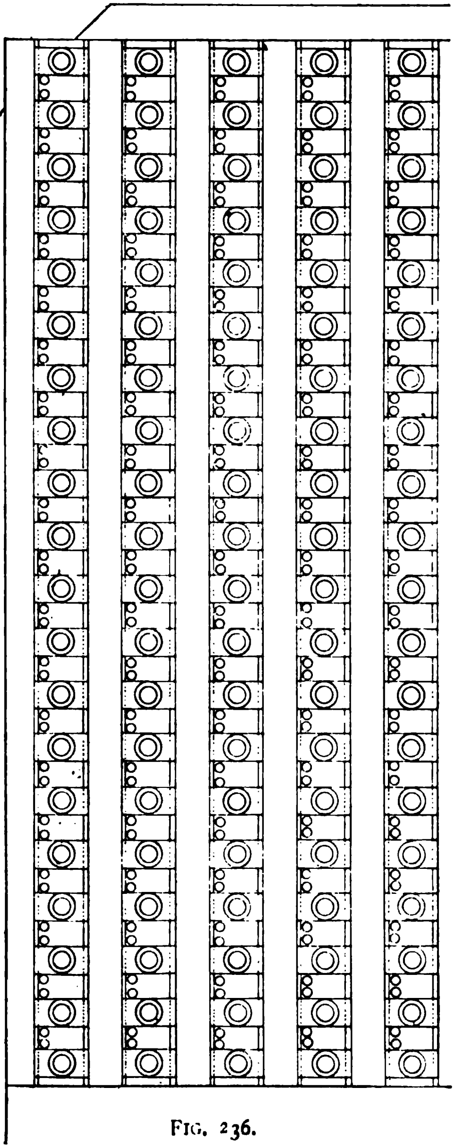


FIG. 236.

small holes in the ebonite plates B to the other face of latter, and there connected under the screw and washer to the serrated plates; these are then clamped close to the brass bars. These wires are put on to consecutive terminals, the first that are vacant, *without regard* to the numbers of the subscriber they are connected to.

Other wires are now attached to the terminals D on the front of the board, and run up the small troughs, at the top of each of which is a vertical row of holes. Through which of these holes the wires pass depends upon the number of the subscriber to which it is connected. The wires for all subscribers between 1 and 300 pass through one of the first holes from the bottom; those for numbers between 300 and 600 pass through one of the second holes from the bottom, and so on, rising one hole higher for every three hundred in the number of the subscriber.

The wires, after passing through the holes, are carried horizontally along the back face of the test-board, round the corner to the top of the front face of the cross-connecting board, and then down and through one of the holes at top of latter board to the proper vertical row of terminals down the back of this board through a hole in the ebonite to its proper terminal, which is numbered the same as the subscriber's number. The wires are guided along their course and kept in position by brass pegs with ebonite tubes slipped over them.

179. *The Utility of the Combination.*—We will suppose the wires from a certain district are brought to the central office in a cable of, say, twenty wires; these will be taken through the trough on to the test-board and attached

to the first twenty spare terminals, although the numbers of the subscribers to which they run may be very far from being consecutive. Separate cross-connecting wires are then run to their proper numbers on the cross-connecting boards, and all is done without touching any of the wires already connected. Or perhaps a subscriber No. 158 changes his address to such a distance that a new wire is required to be run: the leading-in wire for this is run on to the test-board and attached to the first spare terminal, the old cross-connecting wire is detached at both ends and pulled out, and a new one run to the new position on the test-board. The old leader is left on its terminal on the test-board and again brought into service when the old wire is utilized for a new subscriber. So it will be seen that any change made in the outside wires is corrected by running new connections between the terminal boards, which is a very easy matter compared with the changing of the leading-in wires, to say nothing of the order and regularity attached to the system.

180. It is necessary to keep a record of the positions of the wires on the test-board in order to be able to find any subscriber's wire thereon without trouble.

This is effected by keeping a book into which two numerical lists are kept posted. The first is the subscribers' list, opposite each name in which is entered in an adjoining column the number of the spring on the test-board to which the corresponding wire is attached. The second one is a list of the springs on the test-board, having in an adjoining column the subscribers' numbers whose wires are attached. There is also an additional column for the record of changes. Specimens of these lists are given below:

Subscriber's No. and Name.	Test Board No.	Changes.	Test Board No.	Subscriber's No.	Changes.
150	802		460	1300	
151	570		461		79
152	1320		462	470	
153		1400	463	22	
154	960		464	49	

Besides the advantages before-mentioned, this system has a further one: inasmuch that, as the wires change their relative positions to each other in the different portions of their journey from outside to the switch-board, it seldom happens that the wires of any two subscribers, having consecutive numbers, run parallel to each other, therefore the induction between any such pair of wires is very small.

CABLING OR WIRING OF SWITCHBOARDS.

181. The method of cabling hitherto followed in connection with the multiple boards, besides requiring a large trough for its stowage, interfering materially with the facility of getting at the indicator drops, etc., at back of the table, gave rise to a great deal of speaking induction, putting a limit to the number of sections which it is possible to work successfully in any one centre, and forms the great drawback to the multiple system.

It will be evident, then, that as the new method only needs one-half the length of cable, it becomes possible to successfully work an exchange of much larger dimensions, or one of the same number of sections with much reduced inductive effects, and at only one-half the cost of cable.

182. *New Cable.*—The cable used for the purpose is much improved. Instead of using separate cables for the speaking and test wires, oval-shaped ones are made containing double the number of wires for the two purposes, the two sets being distinguished by their covering being of different colours. They are also twisted together in pairs, one speaking and one test wire. One reason for this is, that there is a possibility that in the future the system may be worked with metallic circuits, in which case the test wires of the switchboards would be used as the return, and, being twisted round the line wire, would be in the best condition for preventing all inductive influence. Used, however, in conjunction with a single wire circuit system, such an arrangement of the wires minimises the induction by keeping the wires further apart. The cables are also sheathed in lead, which is connected to earth.

In the new method the cables run direct in a straight line from one set of spring-jacks to the corresponding set on the next section, and this is done without interfering with the practicability of getting at the spring-jacks, which it is necessary to do from time to time, in order to clear faults.

183. *Mode of Connecting up.*—This is done on a long bench, which should, if possible, be the full length of the switchboards to be connected; but if this cannot be managed, the work may be done in sections on a shorter

one. Blocks D D Fig. 237, are screwed to this bench at exactly the width of one of the sections of the switchboard apart (which in the Manchester Boards is 6½ feet). A spring-jack strip is then screwed to each of these blocks, and each of the strips must be numbered the same. Behind the strips, at a varying distance, but in the shortest of 1½ inches, is fixed a regulating block, F F, on the top of which slots are cut, and midway between the slots twenty pegs are projecting at the same distance apart as the sockets of the spring-jacks. At each end of these regulating blocks clamps are screwed, and all is ready for the cable.

The cable is cut into lengths sufficient to reach from the extreme left-hand spring of one strip round the end peg of the regulating block to the next block on the right-hand side, and round its extreme right-hand peg to the last spring on the strip, allowing about half an inch extra for soldering. The lead and other outer covering is next stripped from each end of the cable, until the unstripped portion reaches to the clamping blocks, in which they are now fastened, so as to lie straight between each pair, and so that opposite each strip are the ends of two cables.

Standing in front of one of the blocks, the workman takes a pair of the wires from the cable on his left-hand side, bends them round the extreme right-hand peg, untwists the covering from the ends, until the covered portion just reaches to the connection spring of the jack-strip, and then threads the white-covered wire through the hole in the bottom or test-wire spring, and the coloured one through that in the middle spring of the end spring-jack. This is repeated until the whole of the middle and bottom springs have each a wire attached.

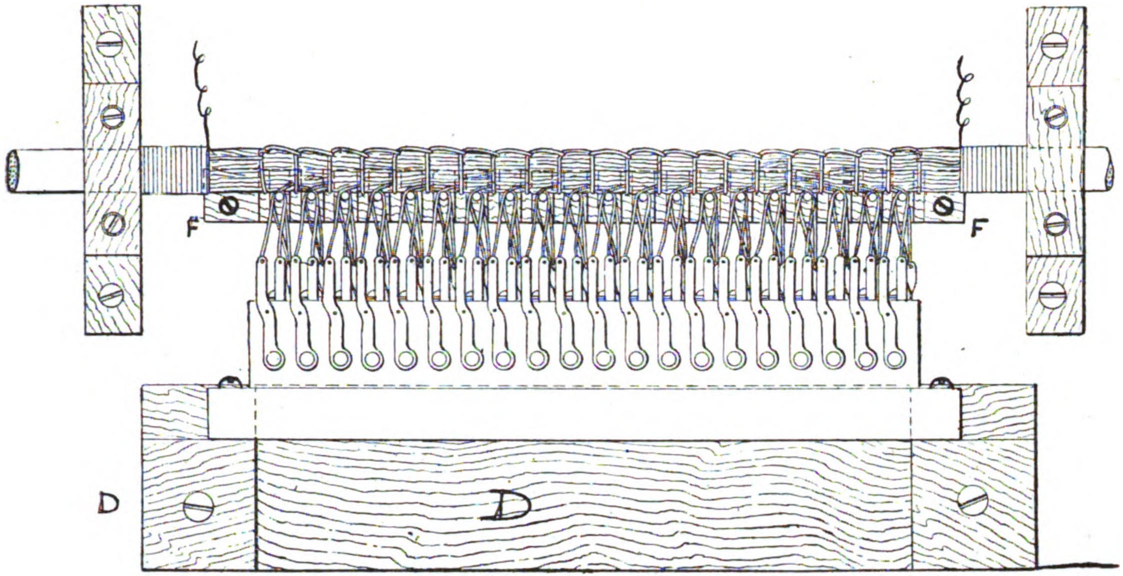


FIG. 237.

The ends of the right-hand cables are now taken, bent round the pegs in a similar manner, and connected to the springs, the white ones to the bottom or test springs, and the coloured to the top ones. It will be seen that each of the bottom springs has thus two wires attached, one from the left and the other from the right-hand cable. The wires are next all soldered to the springs, the loose ends cut off, and the wires at back of the regulating blocks bound together by tape or covered wire, threaded through the slots in the block, so as to form as it were a continuous cable with wires projecting therefrom to the spring-jack blocks. The same process is repeated at each of the blocks along the bench, except that in half the cases the wires put on the springs must be tested, so as to be sure that corresponding spring-jacks on the strips are connected to each other throughout the length.

When all are so connected, the strips are unfastened from the blocks on the bench, the cable lifted off the regulating pegs, carried behind the switchboard, and each of the strips screwed in its proper position on the board.

The connections of the rest of the cables only vary from that described in the distance which is allowed between the jack strips and the regulating blocks when fitting up on the bench is varied. For the Manchester board there were six different lengths, the one mentioned above, viz., $1\frac{1}{4}$ inch, being the shortest. The cables with this length are for the strips that are fitted in the first panels of each of the tables, the ones for the second panel having a length of 2 inches; those for the third, $2\frac{3}{4}$ inches; for the fourth, $3\frac{1}{2}$ inches; for the fifth, $4\frac{1}{4}$; and for the sixth 5 inches, thus lengthening by $\frac{3}{4}$ inch for every panel to the right.

By adopting this plan, the cables when in position lie in a horizontal layer, as shown in the section, Fig. 238, which also shows the arrangement connected to the boards for supporting these cables and keeping them in position. A represents a division board, one of which is fixed between each pair of panels, screwed to this is a steel bar, B, drilled and tapped for the steel pins, C C, threaded at each end and fixed at a distance apart equal to the thickness of the spring-jack strips. Between every pair of these pins six cables are arranged, one behind the other, more pins

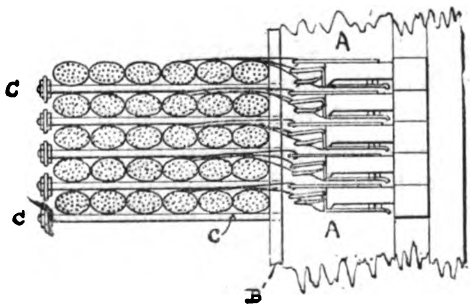


FIG. 238.

being put in as layers of cables are added above. In this manner a very neat and compact mass of cable is obtained, well out of the way of any other part of the boards.

In order to reach any of the jack strips on which a fault has developed itself, a few of the steel pins are unscrewed above and below its position to right and left, when an opening can be made between the proper layers large enough to unscrew and withdraw the strip. Having cleared the fault, the strip is re-inserted, fastened, and the pins refixed between the layers, and all is straight again.

184. *Connections to Boards.*—It will now be necessary to trace the connections of the lines between the cross-connecting boards and the indicator drops, and to explain the nature of an improvement which has been introduced, by means of which the length of switch-board cable through which it is necessary to speak has been reduced, on the average, to less than one-half, and in many cases to much less than a quarter, of that which would otherwise have had to be spoken through. This, of course, means a corresponding reduction in the induction.

On the Manchester tables the general spring-jacks are arranged in sets of 100 at the top part of the tables. Directly beneath these is a double row of strips, the full width of the table, called "local spring-jacks," 200 in number, which are those connected to the indicators of the subscribers whose wires terminate on this table, and into which the operator plugs when answering any of these subscribers' calls. There is also a set of jacks among the general ones for the same numbers as these local ones, so that it will be seen that these are duplicated *on the same table.* This is so arranged in order that the cords may not have to extend across the table in connecting, as would be necessary without them, and also to give uniformity to the tables.

The usual method of joining up these spring-jacks was to run the cables from the test-board to the proper strip among the general spring-jacks on the nearest switch-table, thence to the corresponding strip on the next table, and so on right through the board to the end, the connections only being made to the spring-jacks among the general ones. After attaching a spare length of cable for future additions, the cable was then brought back and connected to the local jacks, on the table on which the indicators of the subscribers to which the wires belonged were situated. Short wires then connected from the local jacks to the drops below. The effect of this was that two subscribers connected together on any table would have to speak through a length of cable equal to more than double the total length of the boards. As already stated, this is a great disadvantage, and any method of reducing this length is deserving of attention, more especially in a large exchange.

The method adopted to accomplish this was to join up the local jacks *on the way* with the ordinary ones; that is to say, to join them up between the two nearest sets of the same numbers among the ordinary jacks. This, although appearing simple enough, was by no means easy to carry out in practice, with the new method of cabling, without interfering with its practical value. After a great deal of trouble, however, it was carried out by the use of very thin cable, in which the wires are insulated by wrappings of silk only; so that connections between subscribers made on any table of the Manchester board are only through a length of cable equal to double the distance between that table and the cross-connecting board, which for the first tables is only a small proportion of the length spoken through with the old system.

185. *Table Switches.*—The switches used on the table at Manchester for the insertion of the operators' telephones into circuit with any pair of cords is also of an entirely new pattern, as will be seen from Figs. 239 and 240.

It will be seen that when the lever, A, is pulled over in the way shown, the two double springs, B and C, are pressed by the projecting ebonite piece, D, into connection with the lower contacts, E and F respectively, which brings the operator's receiver, transmitter, and test-cell

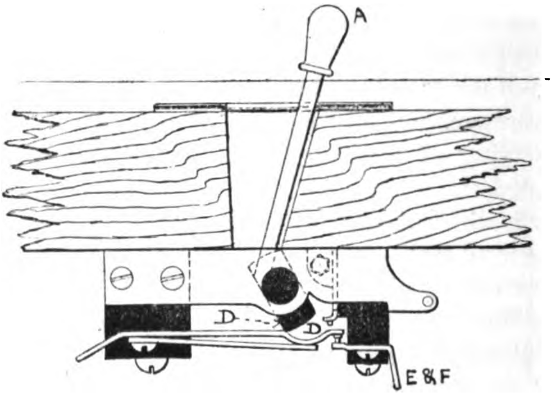


FIG. 239.

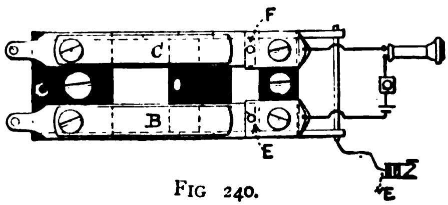


FIG 240.

into circuit with the pair of cords, to which the springs of the switch are connected. By pressing the lever over the other way, the double springs come against the two top contacts, between which the ring-off drop is connected. This drop is connected up in derived circuit instead of in direct circuit.

186. *Switchboard Transmitter Supports.* — A new pattern of these has been adopted, which consists of an upright standard fastened by screws to the top of the table, and through the head of which passes a horizontal arm, about 18 inches long, which can be moved backward or forward, and clamped at any position by a binding screw. At each end of this arm is a cross piece, with two ebonite pulleys about 3 inches apart, and at the sides of the head of the upright piece are also pivotted two similar ebonite pulleys.

Two conducting cords (which may be uninsulated) are threaded over the six pulleys, one pair of ends being connected to the transmitter terminals, and the other pair, after passing under two ebonite pulleys on the top of a lead weight double the weight of the transmitter used, are attached to terminals fixed at back of the switchboards, which are connected to induction coil and battery. If the induction coil were contained in the case of the transmitter, it would be necessary to use double flexible insulated cord for the connection.

By this arrangement the transmitter can easily be adjusted, in regard to distance from front of table, or as to height, and can in a moment be pushed above out of the way when not in use, and instantly brought down again when required.

187. *Trunk Lines.*—As before stated, much attention has been paid to the working of those wires connecting the surrounding and distant towns with Manchester. Several novelties have been introduced, and the completeness of this trunk system may be judged on reference to the map.

The wires from the outside towns are first brought on to the test-board, the same as other wires. In most cases, where there is more than one wire to any one town, they are divided into those which are to be used for calls originating in Manchester, and those to be used for calls *to* Manchester. The latter are put on the ordinary multiple trunk table, and worked in the ordinary manner; and the former are connected to *special* trunk tables. About twenty lines are connected on each of these

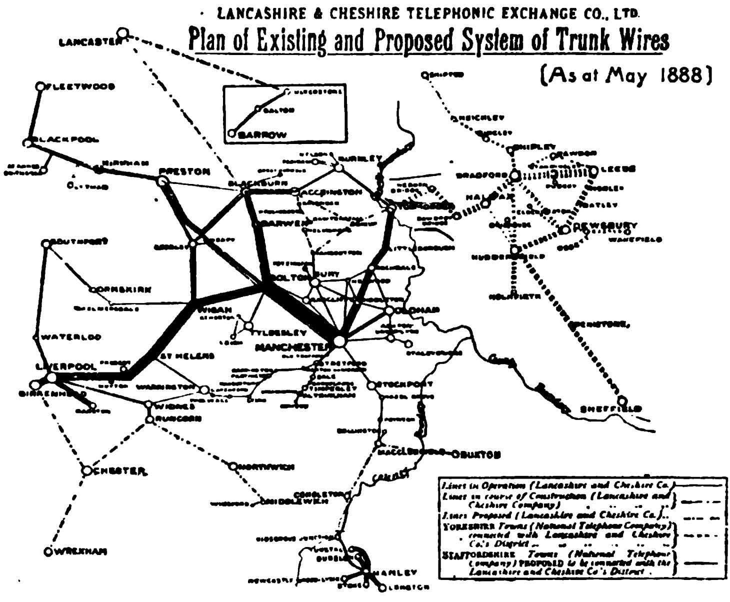


FIG. 241.

tables, of which there are three, and two operators attend to each.

Twenty spring-jacks on each table are connected to single cords on the trunk multiple table, and numbered correspondingly. Through these the trunk wires are switched on to any of the local subscribers these connections being made by an operator stationed in the centre of the trunk multiple board, who is always listening on, and receives her instructions through a wire connecting her telephone to the special boards, to which the operators on the latter can connect by the simple movement of a switch.

188. *Busy Trunk Subscribers.*—A special arrangement is, however, made in the case of those local subscribers who use the trunk wires very frequently. In such cases their lines are *multipled* on the special trunk boards; that is to say, their lines are taken from the test-board to multiple spring-jacks on these boards, arranged in a centre panel, and then pass to the multiple jacks on the ordinary boards and back to indicators, test wires being also connected, so that the trunk operators can test if their lines are engaged. By this arrangement they can connect direct, just as though they were on an ordinary multiple table, without the service of the listening operator before mentioned.

When a local subscriber speaks to one in a distant town, a charge is made and a ticket has to be made out, showing to whom the charge has to be made and the town and number required. It was usual, in other exchanges using the multiple boards, for these tickets to be written by the ordinary operators; but it was evident that this caused much delay in the answering of their ordinary calls, and, as the trunk operators had too much to do without writing, a special plan was arranged by which a subscriber requiring a connection to another town mentions the word '*trunk*' to the ordinary operator, who immediately connects him to a table at which a clerk is sitting, whose sole duty is to write out these tickets. When the calling subscriber gives the necessary particulars the clerk rings off, and the line is restored to its normal condition. The ticket made out is then stamped by an automatic time stamp, made by the Western Electric Co., and passed on to the trunk operators, who, when a line to the town wanted is disengaged, make the connection in the manner before described.

This method, although reading somewhat complicated, is in reality very simple, and results in the trunk wire service being carried on very smoothly.

189. *Time Check.*—An arrangement has also been devised by which the trunk line connections can be regulated in regard to their time duration.

By means of one small clock, a disc over each of the trunk wire indicators is so arranged as to fall at the end of the time allowed for conversation, and either automatically disconnect or call the operator's attention, so that she may disconnect or make a further charge for the use of the wire.

This relieves the operators of a great deal of anxiety as to the length of time subscribers have been connected, and as to when they are entitled to disconnect.

CHAPTER XXI.

INTERCOMMUNICATION BETWEEN TWO DISTANT TELEPHONIC NETWORKS.

SYSTEM OF TRANSLATION.

190. THE rapid spread of telephonic networks renders the question of direct communication between subscribers in two distant towns of great importance. A telephone system can hardly be considered complete that does not provide such communication, and the extent to which this is carried may be seen in the large number of trunk wires which have been established, especially in England, Germany, and Switzerland. The system of the Lancashire and Cheshire Telephone Co. has already been referred to, and, under the National Telephone Co.'s system, towns so distant as Edinburgh and Glasgow, 55 miles; Glasgow and Ayr, 53 miles; and Edinburgh and Falkirk, 32 miles, have direct telephonic communication.

Now where these connecting lines are single and of considerable length, induction is a most disturbing element, rendering communication difficult and almost impossible. Where there are only a few wires the conversation carried on upon other wires can be overheard in each, and with a great number of wires the confusion of sounds makes communication hopeless. The only known method of getting over the difficulty is by employing a return wire instead of an earth return.

In this case, however, if double lines are used for the connection of two distant central stations, the lines of all the subscribers using the connection must be constructed double also? Such an arrangement is very expensive, and so, to a considerable extent, decreases the usefulness of the system.

The solution of the difficulty has therefore been sought in a different direction, and transformers have been placed at the terminals of a double line connecting two central stations, which render it possible for two subscribers, each connected by a single line with the distant central stations, to enter into direct communication through a double trunk wire.

Such arrangements have been introduced among others by Bennett, Nyström,* and Elsässer.†

(a).—*BENNETT'S SYSTEM.*

191. The induction coils used for the purpose are of special construction. The ordinary induction coil, having a primary of small, and a secondary of large resistance, will not do. Both the helices of a translator must be of high resistance, and each operates alternately as primary and secondary, according to the direction—out-going or in-coming—of the current. Mr. Bennett originally used helices of equal resistance, but he finds it better to wind them in the proportion of 1 to 2·5. The core of the trans-

* Journal Télégraphique, vol. VII., p. 208.

† Electrotechnische Zeitschrift, vol. III., No. 12., p. 505.

lator must be of the softest iron wire, and, to obtain the best results, the coils must be wound as closely as possible and with the greatest exactitude. When the coils are well made, the strength of the speaking through a copper metallic loop working through two translators is not sensibly diminished. For instance, subscribers in Glasgow and Edinburgh converse together over metallic loops 50 miles long as easily as they do over their local single wires; and much greater distances are occasionally worked.

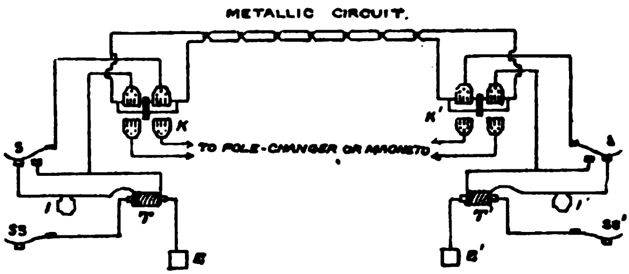


FIG. 242.

Fig. 242 is a plan of the connections adopted by Mr. Bennett in the Edinburgh and other exchanges under his care: T,T' are the translators; I,I' the indicators for calling purposes between the two towns; K,K' are two keys furnished with two upper and two lower rubbing contacts; S, S' the spring-jacks used when the metallic loop has to be joined directly through to another metallic loop; SS, SS', the spring-jacks for connecting the subscribers' earthed single wires. When two such subscribers are plugged on at SS and SS', the current goes from the transmitter to SS, and through one section of T to earth. The speaking is taken up by the second section of T, and travels, by I, S, and K, over the metallic circuit, to K′, through one helix of T′ to I′ and S′, and so back to T. The second section of T′ picks it up and conveys it through SS′ and the listening subscriber's telephone to earth.

To call the opposite station, the operator presses the key until it leaves the top stops and makes contact with the bottom, thus cutting out of circuit the translator and indicator, and putting the pole-charger, or other source of power, direct to the metallic loop, so dropping the other station's indicator. The coils of the indicators should be of as low a resistance as practicable, and connected in parallel.

S, S′ are furnished with two bottom contacts. When the metallic loop has to be joined to another, the resistance and magnetic inertia of the translator and indicator would diminish the efficiency of the speaking if allowed to remain in circuit. The plug is therefore made long enough to touch both contacts when pushed into the jack, and so short-circuits both the translator and indicator. Sometimes it is desirable to retain the indicator in for ringing-off purposes, and the connections are modified accordingly.

(*b*).—*NYSTRÖM'S SYSTEM.*

192. An induction coil, *a b*, whose sections as in Bennett's are adapted to the existing conditions of resistance, is placed at each of the two exchanges A and B (Fig. 243). One of the sections *a*, of each coil, is connected, as shown in the figure, with the double (trunk) line between these exchanges. One extremity of the second section, *b*, is in permanent connection with earth at the central

stations. The ordinary switchboard of these stations permits the connection of any single wire whatever with the second extremity of the winding *b*. Of course the further end of each subscriber's line is, as usual, in permanent connection with earth.

If now subscriber T, connected with exchange A, is put through, by means of the trunk wire 1, 3, to the exchange B, and thence to subscriber T′, communication will be effected in the following way. The current produced when the subscriber T telephones on the local line L circulates through section *b* of the induction coil at A, and exercises an inductive influence on section

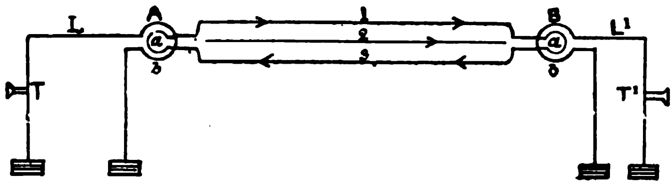


FIG. 243.

a. Hence results, as indicated by the arrows in the figure, a current in wires 1 and 3, whose extremities are connected to section *a*. This current, which at the exchange passes through section *a*, of the induction coil at B, there engenders an induced current through the single wire L′, which connects the subscriber T′. In this way several double lines can be simultaneously employed for telephony, without any confusion arising in the conversation; and besides, *one* conversation can take place by means of a single line between two central stations, although the electric currents between the earth plates of this single line produce a rather troublesome noise.

The figure represents the single wire 2, placed in the middle between the two wires 1 and 3, which form a double line. The wire 2, of course, exercises an inductive action upon 1 and 3, but this action is such that the effect upon one of these wires is completely counteracted by the effect upon the other. In the same way wires 1 and 3 act by induction upon wire 2, but in a contrary sense, and, consequently, without any sensible effect. It is, however, a remarkable fact that wire 2 need not necessarily be placed *between* the two others, but may be placed *outside*.

The intensity of the sound is not weakened to any considerable extent by this double inductive effect. It is found, in fact, that by this double transformation sound is transmitted with at least as much intensity as by ordinary telephony on a single wire.

Of course the currents coming from an ordinary induction apparatus will not produce at the distant station the usual signals, and consequently special calling arrangements between the exchanges have to be made. The most practical is to have a special wire, common to all the trunk lines.

(*c*).—*ELSÄSSER'S SYSTEM.*

193. A similar arrangement has been adopted by Mr. Elsässer between Cologne and Elberfeld, a distance of fifty-seven kilometres, and connected by means of a four-wire cable.

The opposite wires 1 and 3 of the cable were, as in the Post Office system in England, at Elberfeld and Cologne connected with a telephone line going to Barmen, with earth, and with an induction coil (Fig. 244).

With this connection, which only requires one induction coil, transmission of speech is very good between Barmen and Cologne; nor were there any inductive effects noticeable in wires 2 and 4. If, on the other hand, two wires lying next to one another, such as 1 and 2 or 3 and 4, are used for the formation of a double line, troublesome inductive effects immediately manifested themselves.

Now, although this double-line system allows of direct speaking between two stations, it does not, without special contrivances at the two central stations, permit direct calls being made by continuous currents between two subscribers' stations. This could otherwise

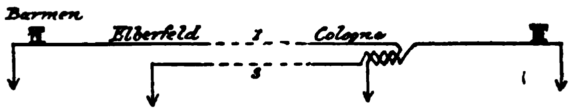


FIG. 244.

only be done by strong alternating currents. But, even where such currents are, by means of inductors, sent from the subscribers' stations, they are, by the double transformation in the induction coils of the central station, as used in Bennett's system, weakened to such an extent that the signals at the called station are very indistinct.

In the same way, the connection shown in Fig. 244 would require alternating currents for calling. If such currents are not available for calling, nothing remains but to effect the calls through the intermediary of the central stations, or else—and this will be found more advantageous for the working—to provide the latter with transformers for the call currents.

The following arrangement has been suggested by Mr. Elsässer, allowing the direct call of a distant subscriber :—

At the central stations I and II, Fig. 245, are the plug-holes k_1 k_2 and k_3 k_4 ; the relays R_1 R_2 with batteries B and B_2, and two induction coils, J_1, J_2. If a subscriber M of central office I, whose line is connected to the electro-magnet system S *m*, wishes to speak with a subscriber of central office II, the central office I first calls station

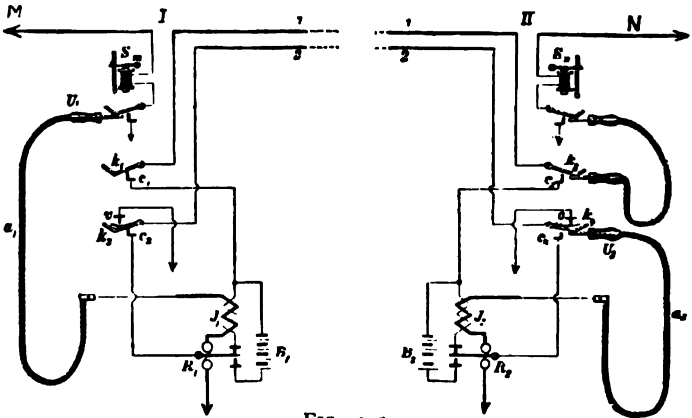


FIG. 245.

II, states the requirement (say, to put through to N), and then connects up its transformer system by insertion of plug U into the plug-hole of S*m*. Central station II at once joins plug-hole S*n* of subscriber N with the plug-hole k_3, whilst the plug U_2 remains at k_4. A call current coming from M circulates through S*m*, U, induction coil J_1, and the coil of relay R_1. The relay tongue is thereby attracted against the lower contact, and closes the circuit of battery B_1. The current from this latter then flows, on the one hand, through the relay lever, plug-hole k_2, the branch 2 of the double line, and through plug-hole k_1 and its special contact spring, v, to earth; whilst, on the other hand, at central station I, it passes from plug-hole k_1 and branch I of the double line to plug-hole k_3 of station II, traverses the electro-magnet Sn, and thence to the line of the called subscriber. The annunciators thereupon fall at both stations, exhibiting the corresponding numbers. Speech is then carried on by means of induction coil J_1, in which the undulatory currents from both stations are transformed whether the talking proceeds from M or from N. That coil only is used which is at the central office of the calling station; if N had called, the calling and speaking would be carried on through relay R_2 and induction coil J_2. This arrangement, it may be noticed, permits of a call from *one* of the two sides only, as will easily be seen from the sketch. As, however, this arrangement is designed for the German system, where the clearing-out signal is given by the calling subscriber only, its adoption leads to no practical difficulty.

It will be observed that, although two wires are used for the trunk line, they are not, as in Bennett's system, used as a closed circuit, but only as a single wire of greater length; in fact, the line of the called station is lengthened by double the distance between the near central station and the central station of the calling subscriber. The induced currents from external circuits are, however, reversed in the two sections I and 2, and so neutralize each other.

There is another arrangement on this system which is simpler still, and which enables each subscriber, after connection has been made, to call. It will be understood from Fig. 246.

The calling current from M passes through the coils of the annunciator of the calling subscriber at the central station I, causing the indicator to drop, thence through U_1, the tongue of relay R_1, and through the coils of the second relay R_2, to earth. The tongue of relay R_2, being attracted against the lower contact, battery B_1 is thereby placed in the circuit of the trunk wires 1 and 2 to the central station II, and the current traverses the electro-magnet coils of relay R_3, the tongue of which, moving downwards, joins the battery B_3, whose one pole

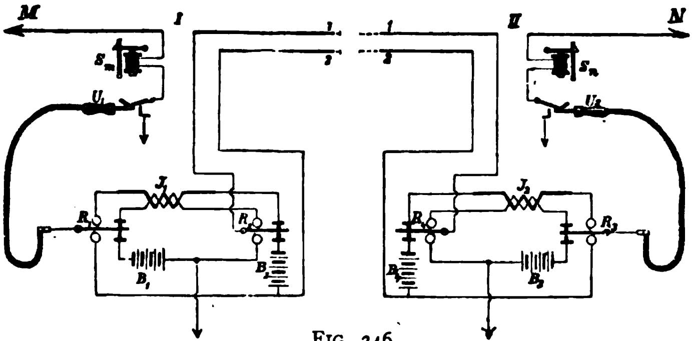


FIG. 246.

is to earth, to S*n*, and line, so that the call-bell of the subscriber's station N will ring.

The speaking currents arriving from M flow, as will be seen, through S*m*, U, the tongue of relay R_1, induction coil J_1, and through the coils of relay R_2 to earth.

The currents of the second order induced in the secondary coil pass to the line wires 1 and 2 through the tongue of relay R_2 and the coils of R_1, and then traverse the secondary coil J_2. The currents of the third order induced in the coil J_2 then pass into line N. In this case the trunk lines are used as a metallic circuit.

Both these arrangements, therefore, (Figs. 245 and 246), permit the sending of direct call signals without the employment of strong batteries at the subscriber's house, or the use of strong alternating currents, and at the same time eliminate the effects of induction upon the long trunk lines.

CHAPTER XXII.

PUBLIC TELEPHONE STATIONS.

194. At these stations, a number of which are now in general use in many countries, all persons without exception, whether subscribers or not, can, on the payment of a certain fee, talk for a specified time with any of the subscribers to the telephone system.

In Germany, for instance, the fee is fifty pfennig sixpence) for five minutes' conversation.

Such stations generally form part of a post or telegraph office where tickets of fifty pfennig each are issued, entitling the purchaser to five minutes' conversation. If the conversation lasts longer, he must either take more than one ticket, or pay an additional proportionate amount at the termination of the conversation.

The working itself is identical with that of other telephone offices. The operator in charge of the public station in the first instance rings up the central station, states what connection is required, and, as soon as he receives a reply, informs the would-be correspondent, who then acts in the same way as an ordinary subscriber does from his own house. A list of subscribers is ready at hand for the use of the public.

Now, besides these stations, which are public in the full sense of the term, there are certain institutions of a quasi-public kind, but reserved to subscribers only, as, for instance, the so-called *telephone cells*, or *silence boxes*, as we call them in England, at the Berlin Stock Exchange. These installations enable a subscribing member of the Stock Exchange to converse during business hours with any subscriber to the telephone system in the town.

Such an installation requires the provision of cabinets which are sound-proof, so that any conversation carried on within cannot be overheard by persons outside. In Germany these cells, or cabinets, are made of double wooden partitions, the space between the boards being filled with a well mixed mass of clay and shavings. The cell can be fastened both from the inside and the outside, and has a window in one of the side walls which is double glazed, so that there is a layer of air between the two panes. The lighting is done from the outside by placing a gas flame in front of the window.

The interior walls of the cell are, in the first instance, covered with a layer of thin pasteboard; on top of this is placed a layer of felt, fastened to thin wooden ledges (so as to obtain a layer of air between the felt and the pasteboard), and, lastly, common wall paper, or a thin cotton stuff, is used for the final covering.

The cell is 1·6 metres deep, 1·3 metres broad, and 2·25 metres high; the corresponding dimensions of the interior space are 1·5 metres, 1·1 metres and 1·85 metres.

There are sixteen cells at the Berlin Stock Exchange which are of different construction, being made of brickwork and being quite independent of one another. All the cells are locked, the operator in charge having the key.

Each cell is provided with an ordinary telephone set with microphone, and a small desk for taking notes.

The call battery may be common to several cells, and be placed outside. If the cell stands against the wall of a room, a separate back wall may be dispensed with. A ventilator of some sort is indispensable.

The cell must be sufficiently sound tight to prevent any person outside, when standing quite close to the cell, from overhearing any conversation inside, even when carried on in the loudest tone of voice; and by the same means the noise from the outside is rigidly excluded, so that the correspondent within the cell can talk without any hindrance or disturbance.

The following is the method of working:—

The person entering the cell presses the call button, and rings up the central station, informing the latter of his wishes. The central station thereupon connects him with the called subscriber. There is the other possibility of a subscriber of the telephone network wishing to call a member of the Stock Exchange; in this case the distant subscriber acquaints the central station with his desire, and the latter communicates with one of the officials in charge of the cells, who sends a messenger with a printed notice to the called member of the Exchange, informing him that he is wanted for a conversation in one of the cells.

In large Exchanges, such as that at Berlin, a separate room is reserved for the official in charge, and provided with a switchboard and with several telephone sets.

195. The arrangement of the switchboard will be understood from Figs. 247 and 248, which represent parts of the apparatus.

It contains twenty-five double plug-holes, constructed in such a way that the two springs rest on a *common* metallic piece. The two plug-holes are alongside each other.

The wires leading from the central station to the Stock Exchange are connected to the left-hand springs (left white in the figure), whilst the wires leading to the cells are connected to the springs on the right-hand (marked black in the figure).

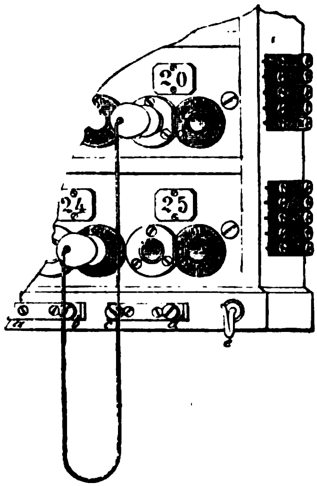


FIG. 247.

As will be seen from Fig. 248, each line is connected to its respective cell when *no* plug is inserted.

Let us suppose, as indicated in the figures, a plug to be inserted into line plug-hole 20, and the second plug of the connecting cord into plug-hole 24; the line 20 is connected to the apparatus of cell 24. In this way any of the lines can be connected to any of the cells.

A control telephone is suspended to hook *e* (Fig 247), another to the left of the apparatus.

The connecting wires of the speaking telephone are fixed to the terminals *b* and *c*, whilst the terminals *a* and *d* carry cords provided with one plug each. If one of these plugs is inserted into a line plug-hole, and the other into a cell plug-hole, the control telephone is brought into line, because the current now finds its way through line, through the plug, and the metallic piece connecting the terminal screws, and thence through the telephone to the second metallic connecting piece

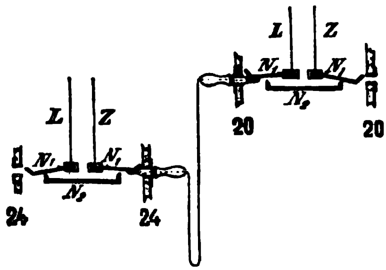


FIG. 248.

and through the second cord to the special line of the cell.

The working is effected in a manner similar to that already described, but with this difference—that the official in charge, as soon as a cell has been placed at the disposal of a subscriber, calls the central station by means of the exchange service line, requesting it to connect the exchange line No. *n* with the line *x*, so that the person entering the cell generally finds the connection already made, and can immediately ring up the desired correspondent.

The use of the telephone cells (also by calling a subscriber from a terminal station) is only open to those subscribers of the general telephone network who pay an additional subscription for the privilege.

196. The construction of the British Post Office silence cabinet has been already described (p. 230). These cabinets are in most cases lighted by an electric glow lamp, which, by means of a switch beneath the seat fixed in the cabinet, is lighted only when someone is seated in the cabinet.

AUTOMATIC CALL BOXES.

197. The automatic box has been introduced in Manchester so that the public can have the use of the telephone exchange by paying for each conversation; and, where it is so desired, subscribers to the telephone exchange can have the same use free of charge.

It is usual to fix these at important points in cities and towns, having them connected by a wire to the telephone exchange. No attendant is required; the payment when put into the box is counted at the telephone exchange by the ordinary operator. When anyone who is *not* a subscriber wishes to communicate, he rings the ordinary telephone bell, placed beside the automatic call-box, and tells the operator the number of the subscriber he wants. If that subscriber is free to talk, then the operator informs the party to put in his money—3d., if connection is wanted in the same town; 6d. if in any other town in the district. As the money is being put in the operator counts it, and connects accordingly. When anyone who *is* a subscriber rings, the operator asks him to insert his check, and turn once. This gives the required signal, and the connection is at once made. In places where subscribers are not allowed the free use, the boxes are made without any place for inserting a check.

The box is made with two slits in the top—one for pennies, the other for sixpenny pieces. There are two openings in front for subscriber's checks—one for local, the other for trunk line connections.

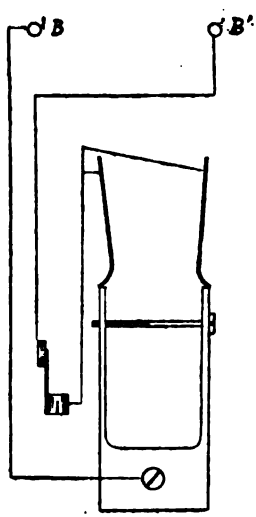


FIG. 249.

198. To give the operator in the exchange the power to do as above described, there is placed in the exchange a relay with local battery and bell. The line circuit of this relay has one end direct to earth, the other is brought to a special connecting plug, having in its circuit a battery of a few cells.

When anyone from a call station tells the operator what is wanted, this special plug is inserted into the line, the indicator is cut off, and a battery current flows to line. The relay becomes closed, and the hammer of the bell rests on the dome. Now, as often as the line wire is disconnected the bell will ring, and it is arranged at the automatic box that each penny shall disconnect the line momentarily through two springs as it drops into the box (Fig. 249). If a halfpenny is put in, it might disconnect one of the two springs; but, in order that the signal may be sent, it is necessary that both springs be acted upon at the same moment, which it is impossible for a halfpenny to do, being too small. A local subscriber's check inserted and turned disconnects the line, and rings the bell in the exchange.

199. If the connection wanted requires that a sixpence be put in, the operator does not use the special plug at the exchange, but keeps the telephone to her ear. The sixpence, in dropping into the box, disconnects the local circuit of the telephone at the call station, that circuit passing through the automatic box. Here, as in the other case, a smaller coin than a sixpence will not operate, and only a trunk line subscriber's check will disconnect this local circuit. When the local circuit is disconnected by a sixpence or a check, a distinct smart click is heard by the operator in the exchange, who knows what has taken place, and then makes the required connection.

200. A modification of the working is, that no relay and bell is required at the exchange, but simply a battery current sent out to line through the operator's telephone; and after a little practice the operator can with perfect certainty distinguish between a noise produced in the telephone by disconnecting the main line with a permanent current upon it, and that produced by interrupting the local circuit. Disconnecting the line produces a noise like a heavy thud, and disconnecting the local circuit a sharp click.

Another modification is that the coin, in dropping into the box at the call-station, disconnects a local circuit having a bell in it, and the sound of the ring is conveyed by the telephone at the call station to the operator at the exchange, who is listening.

CHAPTER XXIII.

1.—*AUTOMATIC CONNECTION REGISTER.**

201. THIS instrument was devised by Mr. J. D. Miller, of the National Telephone Company, Dundee, for the purpose of registering automatically the number of connections made by an operator; long experience having demonstrated that it is in vain to expect the attendants to keep an accurate record with pencil and paper.

The apparatus consists essentially of an electro-magnet, the armature of which engages with a ratchet wheel and moves forward an index which counts up to 10,000. Each switch plug is fitted with a metal boss, which momentarily closes the circuit of a battery through the coils of the electro-magnet of the register whenever the plug is taken from its position of rest for the purpose of making a connection. As each switch cord has two plugs, and each plug makes two contacts for each connection effected, the index reading has to be divided by four at the end of the day, so as to obtain the net number of connections. When each operator in an exchange is provided with a counter, a very perfect register of the traffic is obtainable, and the attendant is left more at liberty to look

* Engineering, 25th March, 1887.

after the switching than when a written register has to be kept. By the combination of a cylinder and a sheet —like those of meteorological recorders—the counter becomes a permanent record of the number of messages passed, and by the aid of a clock it may be made to indicate the time at which they occurred and the duration of each. With this last attachment the instrument becomes of value as a recorder in a public telephone "call" office, when the charge made is proportional to the length of the conversation.

II.—*APPARATUS FOR THE DISTRIBUTION OF TIME IN TELEPHONIC NETWORKS.*

202. This is an accessory apparatus for central stations, and was exhibited by Mr. Oram at the Philadelphia Exhibition in 1884.

It sends every minute interrupted currents into the whole network, which are feeble enough not to interfere with the conversation, but at the same time sufficiently strong to produce a distinct and short sound at regular intervals.

The subscriber, in order to ascertain the time, has only to unhook his telephone and hold it to his ear. Every minute he hears a feeble humming noise which attracts his attention, and immediately after he hears successive signals which give the hour and the minutes.

Supposing he had heard two signals, followed by a short interval, then three and another interval, and, finally, seven signals. This would indicate that, at the moment of the next signal that is to say, in one minute, it will be thirty-seven minutes past 2 o'clock.

The complete apparatus consists of a clock, which makes contact every minute and which actuates a distributing apparatus. Through the making of this contact the drum gears in with the shaft of an electro-motor, which is always in motion, and is fed by a special battery.

On the surface of the drum are fixed, as on the drum of a musical box, a series of pins representing hours, tens of minutes, and units of minutes. These pins, during the rotation of the drum, actuate a lever, which carries a hammer, and the hammer strikes, during one revolution of the drum, as many times as there are active pins on the circumference. At each stroke of the hammer a contact is made by the help of a special battery, and a current of short duration is sent into the line.

By a very simple contrivance there is at every minute another series of pins acting on the lever, so that a stroke is added at each new minute; the total is reached after nine strokes and then the ten of minutes is added. The same operation is gone through automatically for the hours. The electric motor is very simple. Before the poles of a horse-shoe magnet are two coils carrying a commutator on their axis. The movements of the motor itself would be too rapid to directly actuate the drum, and a train of wheels is therefore interpolated between the two, which retards the motion.

A diagram showing the connections is given in Fig. 250: H is the clock, which makes contact every minute, and sends a current into relay A. The armature is attracted and the drum released; at the same time, a small metallic plate, C, mounted on a spring at the extremity of the armature, momentarily touches the screw B, and repeats this contact several times in consequence of the vibrations imparted to it by the shock. Whenever there is contact between B and C, the current of battery P′, passes through B, C, armature L, and then through G and V to all the subscribers' lines which lead to a common earth. For this purpose the connection between the switchboard and earth is broken. Then, all the subscribers which at that moment hold their telephones to their ears hear the humming noise arising from a series of rapid contacts between B and C.

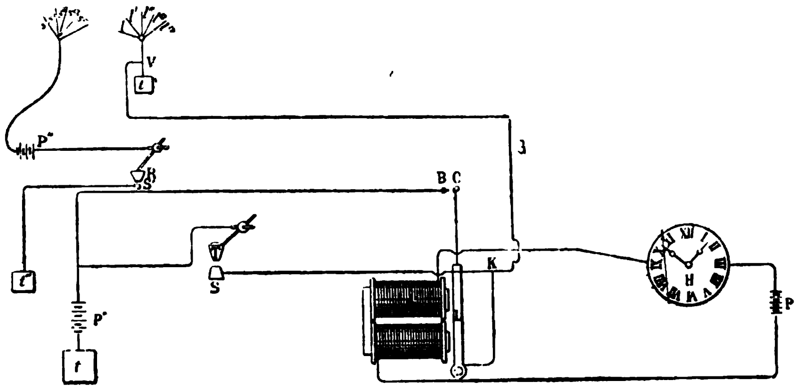


FIG. 250.

Practice has shown that the disconnection of earth has no inconvenience for the central station, and that, consequently, earth can be made on all the lines going to all the subscribers.

The movement of the armature L of the relay A, sets in motion the drum, whose pins cause the hammer T to strike against the contact S, and the number of blows struck corresponds to the hours and the minutes indicated by the clock H. At each blow of the hammer contact is made between T and S, and the current of battery P′ passes through T, S, G, V into all the lines.

Each contact is only of short duration; a distinct sound heard is in all the telephones unhooked from their switches, and the blows of the hammer can be easily counted.

The National Time Regulating Company, of Boston, which works this patent, charges a subscription of one dollar per annum.

203. Oram's system has been adopted at Lowell (Mass.) by the New England Telephone Company. A difficulty, however, has presented itself in practice, which has been overcome in a simple and ingenious manner. It was found that when signals were transmitted to the subscribers who paid their annual subscription, many others could hear, although their wire was not connected to the Oram apparatus.

To prevent non-subscribers from thus sharing gratis in this benefit, a second hammer, R (Fig. 250), has been added, which gives additional signals, producing confusion. To effect this, all the lines S, S′, S″, etc., of non-subscribers are joined together after their passage through the annunciator board, and connected, through a battery, P″, to the "confusion" hammer R. The drum actuates this hammer in the most bewildering fashion. At each blow a current is sent into line, which produces a noise that is rendered as similar as possible to the regular noise arising from induction of the genuine distribution.

CHAPTER XXIV.

MULTIPLEX AND LONG-DISTANCE TELEPHONY.

MULTIPLEX TELEPHONY.

204. THE subject of duplex and multiplex telephony differs essentially from that of duplex telegraphy, since, of two sets of ordinary telephonic currents arriving from a single line, it is impossible to direct one through one telephone and the other through a second. To do that, currents and telephones differing in their nature would have to be used in such a way that each telephone would respond only to the currents intended for it. The efforts of telephonists have taken, therefore, the direction of endeavouring to increase the carrying capacity of metallic circuits, and so to obtain as many working lines between two towns as there are wires. Overhearing and disturbance render this impracticable in the ordinary way, and so at present the plans adopted are such as enable two distinct circuits to be worked over a single metallic loop.

The best American plan is shown in Fig. 251, in which PP, P′P′, are the primaries, and SS, S′S′, the secondaries of four translators, two at each end of the metallic circuit. The primaries of the two at each station are wound differentially, so that out-going currents from T or

T′ splitting between them produce equal and opposite currents in the secondaries, and leave the telephones TT and T′T′ unaffected. But currents originating in TT or T′T′, which are in circuit with the secondaries, induce currents in the primaries, which circulate in the metallic loop, but leave the earthed telephones T and T′ unaffected. Theoretically the plan is right, and experi-

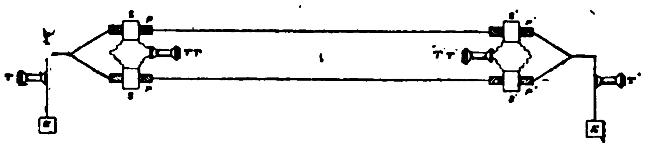


FIG. 251.

mentally it answers well; but, practically, the resistance and magnetic inertia of so many cored translators kills the speaking in the metallic circuit. More especially is this the case when, for switching purposes in an exchange, other translators, making a total of six, have to be substituted for the telephones TT and T′T′.

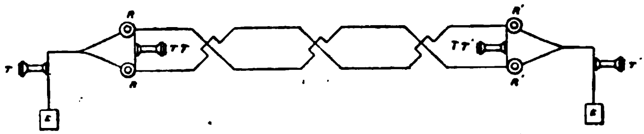


FIG. 252.

205. As far back as 1882 Mr. Frank Jacob, Technical Adviser of Messrs. Siemens Bros., designed a plan by which the principle of the Wheatstone Bridge is utilised. It is shown by Fig. 252. The two resistance coils RR at either end must exactly balance each other; it is not, however, necessary that all four should do so. The wires forming the metallic loop should also balance

in conductivity, insulation, and capacity. When these conditions are attained, T may speak to T′, and TT to T′T′, without the faintest sound of overhearing being apparent. Currents originating at T split between RR, pass TT, on either side without affecting it, traverse both wires of the loop, and join again after passing R′R′ going through T′ to earth. Currents starting from TT have three paths open to them: (1) through RR and back; (2) through one wire of the loop TT′, and back by the other wire; and (3) through one wire of the loop R′R′, and back by the other wire. But the second has by far the least resistance, and, if the metallic loop be of copper, the speaking is quite as good as on an ordinary metallic circuit. The insertion of mere resistance in a single earthed telephone line does not perceptibly interfere with the speaking, so that communication on the earthed section of the system is also good. T and TT may be in different quarters of one town, while T′ and TT′ are in different parts of another.

Instead of being placed at the ends of the metallic loop, as figured, the earthed circuit may be taken off at any intermediate points. Thus, on a metallic loop, say, between London and Brighton, an earthed circuit might be worked between say, Croydon and Lewes. The earthed circuit, however, is practically a single wire, and, like all single wires, is disturbed by induction from neighbouring parallel lines. The metallic circuit is, of course, not so affected. For exchange purposes, indicators and translators, with the usual switching arrangement, are inserted at TT, TT′, instead of telephones. The ordinary ringing devices suffice. This system has been working for some time on the lines of the National Telephone Company connecting the various Cumberland towns, and has also been successfully tried between Glasgow and Paisley, and other places.

Fig. 253 shows a development of the system by which two metallic loops may be made to yield four working circuits. If the route is subject to telegraphic induction, the earthed circuit may be omitted, and the three metallic circuits, T_2T_2', T_3T_3', and T_4T_4' retained. The speaking on the last is weakened by the large amount of resistance it has to traverse, but, if the resistance

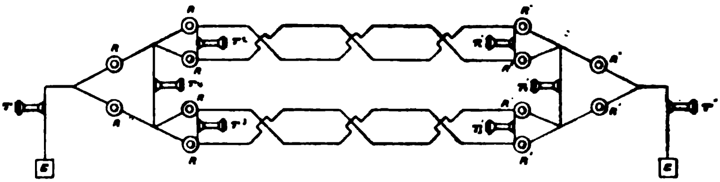


FIG. 253.

coils are shunted by condensers of sufficiently large capacity to transmit speech, it will work as well as the others.

LONG DISTANCE TELEPHONY.

206. It is a well-known fact that telephoning meets with considerable difficulties where several wires, running for long distances upon the same poles, are employed for the service. Through the mutual induction of the currents, a conversation carried on upon one line can be plainly heard in a telephone placed in the circuit of another line running parallel to the former ; and this is not the worst ; the stronger currents used for telegraphing purposes, and passing along the wires stretched between the poles, show their inductive effects upon the telephone wires by producing in the telephone a

sort of crackling noise, which often renders telephonic communication, if not absolutely impossible, yet very tiresome.

These injurious noises are considerably weakened if the telegraph currents, instead of taking a sudden rise and again disappearing just as suddenly (as is generally the case in the ordinary telegraphic contrivances), reach their full strength but gradually, and decrease in the same way.

At the commencement of 1882, Mr. J. F. van Rysselberghe, consulting electrician of the Belgian Administration of Telegraphs, conceived the idea of using the retardation of an electro-magnetic coil inserted in the telegraph circuit in order to prevent the sudden appearance in its full strength of a galvanic current on the closing of the circuit; *i.e.*, on the pressing down of the Morse key. This retarding effect of electro-magnetic inertia of course makes itself equally felt in preventing the sudden disappearance of the current on breaking the circuit—when the Morse key is released.

Van Rysselberghe, in the first instance, inserted between the front contact of the Morse key and the battery-pole connected to this latter an electro-magnetic coil with an iron core. The sound obtained at the closing and opening of the circuit in a telephone placed in this circuit is hereby considerably weakened. This weakening effect is still further enhanced if, according to a further suggestion of van Rysselberghe a second electro-magnet is inserted between the key and the line, and a condenser between the line terminal of the key and the pole of the battery which is connected to earth.

This arrangement is shown in diagram in Fig. 254.

L, line; T, Morse key; M telegraphic receiver; J, J electro-magnets; B, battery; C condenser; E, earth.

By depressing the key the condenser is charged; and a certain quantity of electrical energy is expended for this purpose at the moment of closing the circuit, the current can consequently reach its full strength only on completion of the charge of the condenser. On opening the circuit, by the release of the key, a discharge of the condenser ensues; the energy stored in the coating of the condenser flows into the line, when the connection between the battery and the line is broken, and thus the sudden disappearance of the current from the line is prevented. It is true the periods of time requisite for the charging and discharging of the condenser are very minute, but yet they are sufficient, in conjunction with the retarding effect of the inserted electro-magnets, very nearly, if not altogether, to obviate the sharp crackling noise of induction.

Fig. 1.

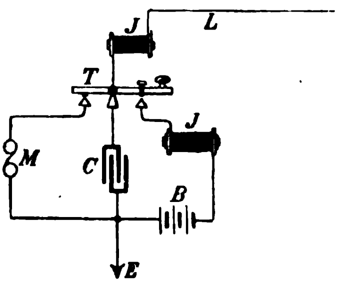


FIG. 254.

It has been found by experiment that the most favourable results are obtained with electro-magnets of 500 ohms resistance, and condensers of two microfarads capacity.

The gradually rising and gradually disappearing battery currents naturally produce induced currents in neighbouring parallel lines; but although these currents throw the membrane of a telephone placed in any line into vibration, the sounds resulting from these vibrations are no longer distinguished by the disagreeable crackling noise. If the arrangements are properly carried out, the sounds are damped down to such a degree that telephonic conversation is in no way disturbed.

207. While making these experiments the idea occurred to van Rysselberghe whether it might not be possible, by a convenient arrangement of the above apparatus, to work the telegraph and the telephone on one line, and he solved this interesting problem in the following way:

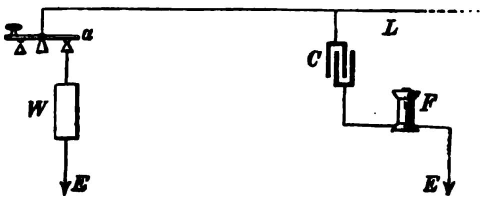


FIG. 255.

If the end of a line is connected to one of the coatings of a condenser, and a telephone is connected between the second coating of the condenser and earth, and a similar arrangement be made at the other end of the line, the two stations can converse without any hindrance. If in front of the condenser (Fig. 255) the line is joined to earth through a resistance W it will be found that telephonic conversation is in no way disturbed by an alternate making and breaking of contact at *a*. If, in place of the key and resistance W, the apparatus shown in Fig. 254 for the levelling of the current waves are employed, telephonic communication will not be interfered with by the currents required for the working of the telegraph. The problem of simultaneous telegraphing and telephoning on a single line is thus virtually solved.

The arrangements necessary for such working are shown in diagram in Fig. 256. The telephone stations F_1 and F_2 may of course occupy separate localities from the telegraph offices I and II. The interpolated separating condensers, C, have a capacity of ½ microfarad.

If, in addition to the line which is to be worked on the combined system, other telegraph lines are erected upon the same poles, every telegraph office upon each of these lines must be provided with a similar set of apparatus, even if only the first-named line is to be used for simultaneous telephony and telegraphy.

If a second telegrap line is fitted up in the same way for simultaneous telephony, telephonic communication is not disturbed by the telegraph service, but another drawback is encountered, namely: a telephonic conversation carried on in one of the two lines can be overheard on the other line.

The injurious effects of induction are most easily overcome by employing two conductors joined into one circuit for each individual telephonic connection. This offers no difficulty in the case of a simultaneous use of the lines for telegraphing and telephoning. The connection of a telephone station with another by a circuit formed of two telegraph lines can be made in the way indicated in Fig. 257. Each of the two lines L_1 and L_2 is connected with one coating of the two condensers C, whilst the other coatings of the condensers are joined by

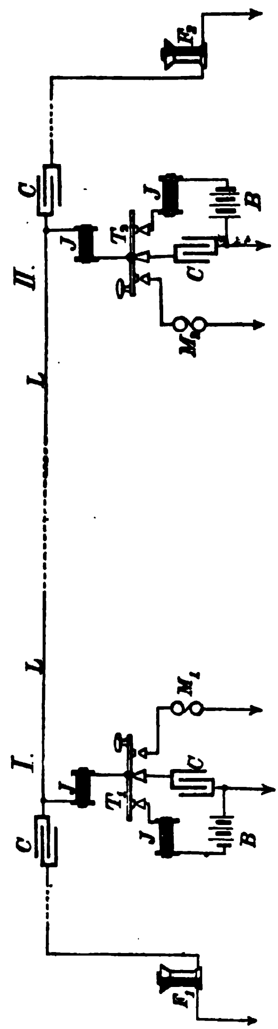


FIG. 256

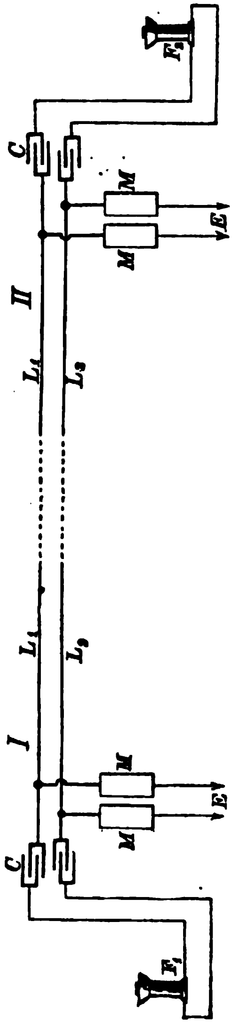


FIG. 257.

wires, on which are placed the telephones F_1 and F_2. Telegraphic communication between I and II is carried on without the least hindrance, and, if van Rysselberghe's anti-induction contrivances are fitted to the apparatus, M M, of the telegraph offices I and II belonging to lines L_1 and L_2, as well as the apparatus of all the other lines upon the same poles, telephonic communication between F_1 and F_2 will not be interfered with by the telegraph service.

208. This arrangement, however, requires a double line for the connection of the individual telephone stations with the central office. To obviate this expense, van Rysselberghe has contrived a transmission between a double and a single line by means of induction coils, and has completed his system by the addition of a telephonic relay (Fig. 258). The telephonic relay FR, which allows of an easier transmission of calls and clearing-out signals, consists of an ordinary telephone, against whose membrane rests a small metallic clapper fastened to the free extremity of a light lever or a thin spring-plate. The membrane and the clapper, insulated from one another, are connected to the poles of a battery. In the circuit of the same battery are also the coils of the signalling apparatus. In a state of rest the battery is short-circuited through the membrane of the telephonic relay and the clapper in contact with it, and only a very small part of the battery-current, therefore, passes through the coils of the signalling apparatus S—not sufficient to set it in motion. If, however, electric currents of short duration circulate in quick succession through the coil of the telephonic relay, the membrane is thrown into violent vibration, the contact between it and the clapper is broken, and connection with the battery interrupted.

The battery current now passes in its full strength through the signalling apparatus and actuates it. By this arrangement the working of van Rysselberghe's system has been greatly facilitated; for, on account of the condensers placed in line which interrupted the metallic connection of the conductors, the calling and clearing-out signals could formerly not be sent in the usual manner.

209. The intermittent currents for the working of the telephonic relay are obtained by the insertion of an

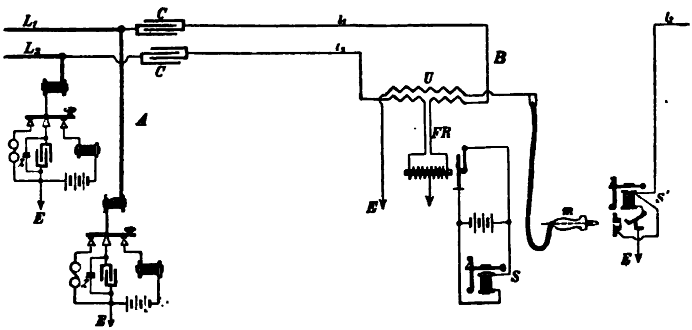


FIG. 258.

automatic interrupter (current breaker) in the circuit of the call battery. Fig. 259 shows the arrangement as adapted to telephone stations.

It is quite clear that this system affords, under some conditions, considerable advantages, dispensing as it does with a separate telephone line. It is, however, generally cheaper to construct a special telephone line than to set up the anti-induction apparatus at each station, which, when used in considerable numbers, introduce a large outlay, besides causing serious retarding influence on the telegraph system.

The following telephone stations in Belgium are now worked with this system:—

Brussels—Anvers, 44 kilometres.
Brussels—Ghent, 57 „
Anvers—Ghent, 80 „

210. Experiments made by van Rysselberghe[1] between New York and Chicago, a distance of 1,010 miles (1,625 kilometres), showed conclusively that the success

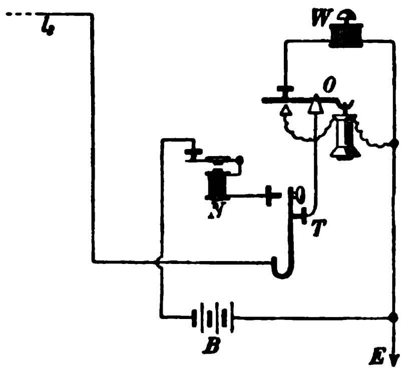


FIG. 259.

of the experiment depended entirely upon the kind of wire used as a conductor.

With *iron* wire conversation could not be properly carried on at a distance exceeding 250 miles, and at a distance of 620 miles absolutely nothing was heard.

The case was quite different with *copper* conductors. Between Fostoria and New York, a distance of 730 miles, a conversation was successfully carried on by means of a copper wire of 2·7 mm. diameter (No. 12). The sounds were rather feeble but perfectly distinct, and

[1] Rapport sur des expériences récentes faites aux Etats Unis d'Amerique par F. van Rysselberghe; Bruxelles, 1886.

S— the most difficult letter in telephonic transmission— could be heard quite clearly.

The same wire between Fostoria and Albany, a distance of 585 miles, gave results which were, even from a commercial point of view, quite satisfactory. In this case the total resistance of the going wire was 3,660 ohms, that of the return wire 3,347 ohms ; the total static capacity of the circuit 3·3 microfarads ; and the insulation 296 megohms per mile.

A thinner wire, of 2·1 mm. (No. 14), at the same distance did not give satisfactory results. A comparison of the results obtained with wires No. 12 and No. 14 showed that, with copper conductors (or any other metal not capable of magnetization, such as phosphor bronze, for instance), the transmitting power of the telephone was, for the same distance and the same conditions, approximately proportional to the conductivity of the wire.

Experiments were made on a circuit belonging to the United Lines Telegraph Company, between New York and Chicago, having a diameter of 6 mm. This is a compound wire, having a steel core of 3 mm. surrounded by copper. The ordinary telegraph service was carried on by all the line wires, and van Rysselberghe's anti-induction apparatus were used for all the experiments, and speech was found to be possible.

To sum up the results—telephonic communication satisfactory even from a commercial point of view, has been carried on :

			Kilometres.
with a wire of	2.1 mm.	at a distance of	500
”	2.7	”	941
”	6	”	1,625

These experiments seem to show that the question of long-distance telephoning has nothing whatever to do with the kind of telephone used, the condition of the conductor alone being the decisive factor. The conditions that influence the distance to which speaking is possible are fully described in § 74.

211. Many experiments have been made in America, as well as in England, to utilize the existing telegraph wires for purposes of telephonic communication, the fact of its being possible to superpose the minute undulatory currents employed for telephone working having been demonstrated by Mr. C. F. Varley in the year 1870. Elisha Gray, Edison, and others have employed systems other than speaking telephones on existing wires with some success; while, in England, Capt. Cardew, of the Royal Engineers, has made an exhaustive series of experiments on this subject with marked success. There are, however, practical and commercial reasons why the ability to speak over telegraph circuits has not been utilized in practice in England.

CHAPTER XXV.

SEVERAL SUBSCRIBERS PLACED ON ONE CIRCUIT (I).

212. THE ordinary system of providing each subscriber of a telephone network with a special wire (in some cases even with two) is very expensive. There are, of course, subscribers who use their wire almost continuously, and these must necessarily have a circuit entirely at their disposal; but the average subscriber does not exceed ten calls per day, so that for the most part of the time the wires are not engaged, and do not even do the tenth part of the work they might easily perform. This is in striking contrast with telegraph wires, which are often utilized to the very utmost; multiple and rapid apparatus being employed to exhaust their capacity, whilst the telephone wires of the subscribers are disengaged during nine-tenths of the time. This consideration certainly shows that telephony is still in its infancy, and that in this direction, at least, important improvements are to be expected.

A number of attempts have been made, with more or less success, to place several subscribers on one wire, and so increase the use of the wire; but there is a great difference in the conditions in this respect between telegraphy and telephony. Nothing is easier than to place several telegraph stations on the same wire, while in telephony the conditions are entirely altered: the subscribers are not officials to whom special instructions can be given; they must not be annoyed by calls which do not concern them; they require that their conversation shall not be overheard by other subscribers on the same line. All these conditions, which require complicated arrangements, do not exist in telegraphy. A thoroughly successful device which would meet these requirements would be a great boon to telephony. In the first place, it would mean a considerable diminution in the number of wires which in large towns cross each other in all directions above the roofs, for it would be possible to serve a much larger number of subscribers with the same number of wires; and, further, the villages which surround the large centres of population might easily be worked with a single wire.

213. The conditions which must be fulfilled by such a system are as follows:—

1. The central station must be able to call each subscriber without disturbing the other subscribers placed on the same line.

2. Each subscriber must be able to call the central station without disturbing any of the other subscribers.

3. When a subscriber is in communication with the central station, or by the help of this latter with another subscriber, it must be impossible for the other subscribers placed on the same line to overhear or to interrupt the conversation.

4. Any two subscribers placed on the same line must be able to converse with one another.

The solutions proposed can be grouped under three categories:—

The first is confined to three subscribers on the same wire or four subscribers on a double wire.

The second is arranged in such a way that the single wire goes to a point more or less distant from the central station, and from this point radiates towards an indefinite number of subscribers (*radial arrangement.*)

The third comprises those systems according to which an indefinite number of subscribers are placed one after the other on the same wire (*series arrangement.*)

(*a*).—*ADER'S SYSTEM.*[1]

214. This system is adapted to the metallic circuit of Paris, and allows of four independent subscribers' stations being placed on a double circuit.

In a state of rest the loop-line is completed at the central station, but is put to earth midway between the four subscribers. When the operator at the central station wishes to call either of the four subscribers, he disconnects one of the two wires and sends into the other a positive or negative current, which, according to the line chosen and the direction of the current, acts on one of the four relays. When a subscriber unhooks his telephone the loopline becomes complete throughout, the earth is disconnected, and telephonic conversation can take its regular course. All this will be better understood by means of Figs. 260 and 261.

Figure 260 represents the four call buttons, 1 to 4, at the central station : A is the annunciator, which enters into action when any one of the four stations calls, and after such a call has been received the operator

[1] "Journal Télégraphique," vol. xi., p. 189.

places his telephone in circuit; L and L′ are the two wires of the loopline or the metallic circuit; B and B_1 two call batteries. A current arriving through L traverses the call buttons 4, 3, annunciator A, call buttons 2 and 1, and returns through L′. When the operator at the central station presses call button 1, a negative current is sent into line L′, and L is disconnected. By pressing call button 2, a positive current is sent into L′. In the same way negative and positive currents are sent into line L by the call buttons 3 and 4 respectively.

Fig. 261 shows the combination of the four subscribers'

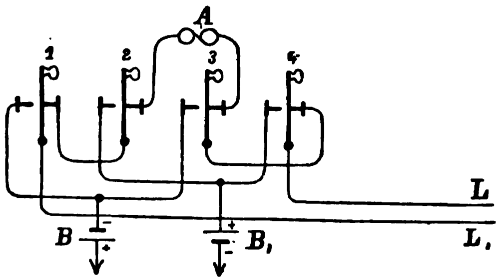


FIG. 260.

stations, I. to IV., in the metallic circuit L L′. Each of these stations consists of a micro-telephonic apparatus, indicated by telephone F, an automatic switch U, press-button T, annunciator S, polarised relay R, call bell W, and a local battery *b*. The four stations have, moreover, a relay R′, and a battery B, in common. The call from the central station traverses the following circuit: On pressing button 1 a negative current presses through L′, and traverses first all the automatic switches U and press buttons T of the four subscribers' stations through the wire *d*, after that it passes through the relays R of the two stations I. and II., and then, by way of Q and the armature of relay R′, it goes to earth. Of the relays R at the two stations I. and II., the one of station I. responds to negative, the other to positive currents; at station I. the circuit of the local battery *b* is therefore closed, and the station is called. When the operator at the central station presses button 2, the current traverses exactly the same path; but it is positive, and consequently actuates the relay of station II, and not the

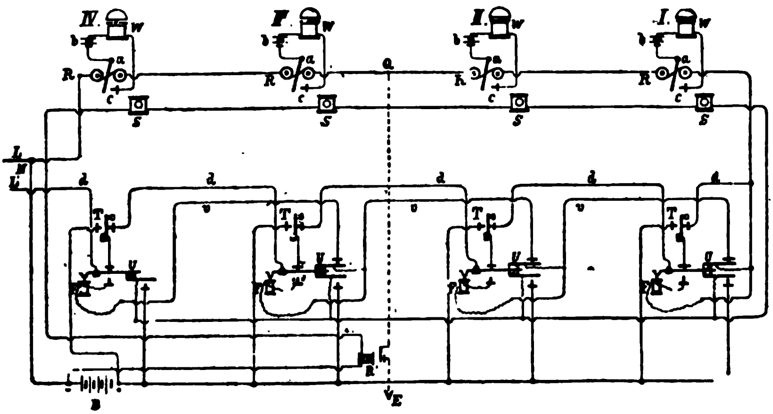


FIG. 261.

other. By pressing the buttons 3 and 4 at the central station negative or positive currents are sent into line L, traverse the relays of the subscribers' stations III. and IV., and return through Q to earth. The negative current actuates the relay of station III., the positive current that of station IV. When one of these subscribers, let us say III., is called, he unhooks his telephone, and thereby completely alters the connections. First of all, contact is made between the positive pole of battery B and the lower plate of the automatic switch, and by this contact a current coming from the battery traverses the four annunciators S. A double purpose is attained by this current. On the one hand the armature R′ is attracted, and the earth connection of the system interrupted; on the other hand all the annunciators which originally showed a disc with the inscription "libré" (disengaged), exhibit now a disc with the inscription "occupé" (engaged). The loopline is complete without earth on either side. The current arriving from the central station through L passes through the four relays, the automatic switches U, and the wire *v* of stations I. and II., telephone F of station III., wire *d* between III. and IV., button T and switch U of station IV., and returns through L′ to the central station. It is impossible to overhear the conversation, for if another subscriber—for instance II.—were to unhook his telephone the circuit would be broken between T and U of station III. When the conversation is finished, and the telephone again suspended, all return to a state of rest. The annunciators again exhibit the disc marked "libré," and Q is again connected to earth.

When one of the subscribers presses his call button T, the positive current of battery B passes through the wires *d*, and the buttons T and switches U into L′, and return directly through S to the negative pole of B.

The relays R and annunciators S are polarised, but they have no electro-magnet; a very flat coil moving between the poles of a very strong magnet replaces the electro-magnet. According to the direction of the current this coil is attracted by one or the other pole, and closes the circuit of battery *b*, or changes the disc of annunciator S. This coil without iron core presents great advantages over a polarised electro-magnet, inasmuch as no inversion of polarity need be feared, either from the currents being too strong or from atmospheric discharges.

The working of Ader's system is most simple: each subscriber effects his call as if he were the only one in the circuit; at the central station also no complication arises, and secret conversation is ensured. On the other hand, some drawbacks have to be mentioned: the remaining subscribers of the same line cannot converse together when one subscriber converses with the central station or another subscriber beyond it; and the other subscribers can disturb the conversation by pressing their buttons or unhooking their telephones. Finally, the communication between the four subscribers requires from six to eight wires; the application of the system has, therefore, for economy's sake, to be restricted to the case where the four subscribers are in the same building.

Mr. Elsässer has succeeded in overcoming the second drawback, but by sacrificing the simplicity of the connections, and since this drawback is not of very great practical importance, it seems doubtful whether these modifications will supersede Ader's original arrangement.

(*b*).—*GRASSI & BEUX'S SYSTEM.*[1]

215. This system is very useful for factory installations where the different offices, or workshops, are sometimes at a considerable distance from each other, and where a great saving results from the employment of a single wire.

[1] "La Lumière Electrique," No. 12, 1885.

The leading feature of this system is the form of polarised relays used. This was shown at the Vienna Exhibition of 1883, and is represented in Figs. 262 and 263.

Part of the calling battery is, as usual, taken for ringing the bell at the calling station. The remainder of the battery is then available for use on a second local circuit, and it is this which gives to the relay its

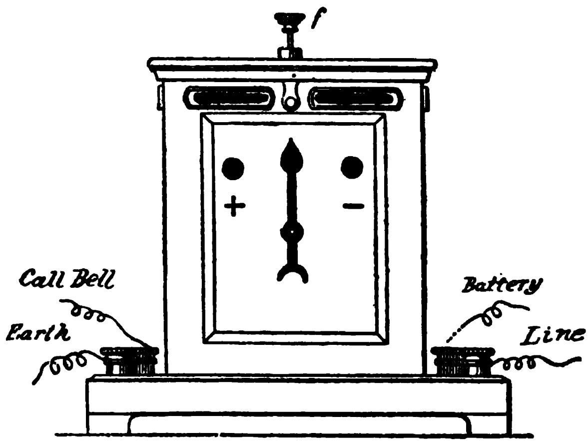


FIG. 262.

special character. This second local circuit serves to magnetize a piece of soft iron which replaces the permanent magnet generally employed in polarised relays. This magnetization takes place through the coil *c* (Fig. 263), and is only produced in case of a call. A′ is a piece of soft iron, which moves to the right or the left, according to the direction of the line current traversing the electro-magnet A B. The advantage of this arrangement is that, whatever the strength of the current which passes into the electro-magnet A B, the polarity of the small magnetic inverter is never changed: an accident often met with on lines of a certain length,

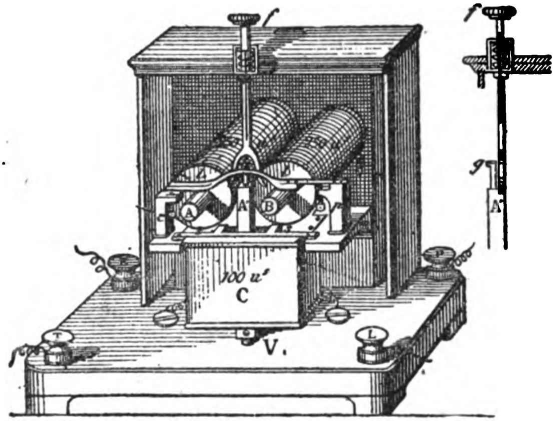


FIG. 263.

during thunderstorms, and in spite of the best lightning arresters. Another point in its favour is the fact (which it has in common with ordinary indicators) that the bell

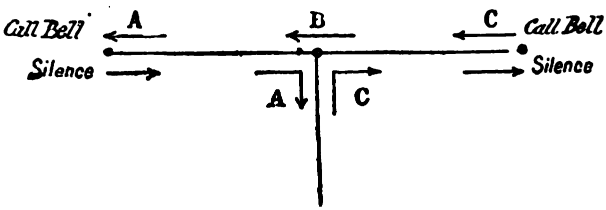


FIG. 264.

rings without interruption until some one has attended to the call.

The principle of the system is shown in diagram in Fig. 264.

At the station B an earth shunt is established. The relay is arranged in such a manner as to disconnect this shunt in a state of rest, and only to re-establish it under the influence of currents of the direction indicated by the lower arrows. In this case it will be seen that a current of the direction of the lower arrows will circulate through the shunt in one sense or the other, according to whether it is sent by A or by C. By placing a second polarised relay in this shunt, it becomes possible to distinguish the calling station.

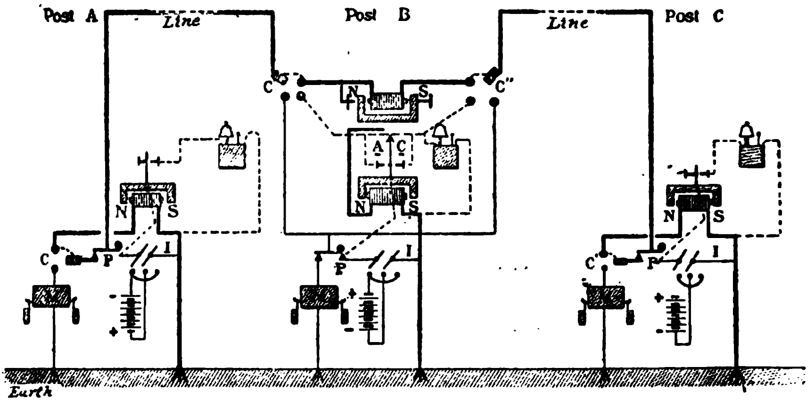


FIG. 265.

Three different effects are thus obtained at station B. The currents of the direction of the lower arrows serve for the calls made by A and C at B. The currents of contrary direction serve for calls between the two terminal stations, traverse B, and there ring the bell.

Fig. 265 shows the connections of the three stations: P are the call buttons, I the pole-changers, M the telephones, and C the switches. At the station B three-way switches are used for the following reason :

Station A must remain silent under the influence of currents of the direction indicated by the lower arrows, which are the currents for calling between B and C. In order to call A, currents of the direction of the upper arrows are employed. But A cannot then distinguish who has called, so A must always reply to a call by simply depressing the button P. If it is C that calls, the answer will always reach it directly, because the battery is so arranged as to give, for instance, currents of the direction of the upper arrows. If it is B that calls, the answer will likewise reach it, although A presses down the button P; because station B, immediately after having called, will press down the centre button of the three-way switch. The current by this means goes direct to the call bell without passing through the two relays. Once the answer received, the third button of the three-way switch at B, the same that had served for the call, is pressed down.

The operations in case of communication with C are similar.

CHAPTER XXVI.

SEVERAL SUBSCRIBERS PLACED ON ONE CIRCUIT (II.).

216. To the second class belong all the systems employing automatic switchboards, such as Bartelous', Sinclair's, Ericsson & Cedergren's, Oesterreich's, Connolly & MacTighe's, Leduc's, etc.

The essential part of this class is an automatic switchboard placed at the point where the subscribers' wires branch off from the single line wire. We shall confine ourselves to the description of those systems which are in practical use at the present time.

(*a.*) *BARTELOUS' AUTOMATIC SWITCHBOARD.*

217. This apparatus, invented by Mons. V. Bartelous, of Brussels, has been arranged both for a double and a single wire service.

First System.

The system which employs a double wire is represented in Figs. 266, 267 and 268. Fig. 266 shows the automatic station, Fig. 267 the central station, and Fig. 268 the subscriber's station.

The automatic switchboard consists of two insulating circular discs A A′, on the circumference of which are arranged metallic contacts 1, 2, 3......1′, 2′, 3′......From these contacts, 1, 1′; 2, 2′; 3, 3′...start the double lines joining the different subscribers' offices No. 1, No. 2, No. 3; on each line wire is further established a shunt *cr*, *ds*, *et*, each of which leads to a flexible metallic strip *r*, *s*, *t*, arranged in form of a comb on an insulating transverse piece G.

Perpendicular to the centre of the parallel discs A A′, are two axes X X, Y Y, the latter of which carries a needle C; a rotatory movement by successive impulses can be imparted to these axes by means which will be explained further on. When such a movement is imparted to the axis Y Y, the needle *c* is successively brought in contact with the points 1, 2, 3. The axis XX carries two needles, B B′; the extremity which carries the needle B traverses the disc A in such a way that this needle turns likewise before this disc, in a plane in closer proximity to it than the needle C, so that it also meets the contacts 1, 2, 3.......The needle B′, placed at the other extremity of axis XX, turns in front of disc A′, and there meets the contacts 1′, 2′, 3′. ...... This axis carries a rod *v v*, which is parallel to it, and provided with a series of points which, when the apparatus is at rest, bear against the strips *r*, *s*, *t*, mounted on the transverse piece G.

Mechanically the needle C participates in the movements of axis Y Y; while the two needles B and B′ and rod *v v* move in conjunction with X X. Electrically the needle B is connected to the axis X X, the needle C to axis Y Y; but the needle B′ is insulated from the axis which carries it, and is connected, by a friction-contact H and a conductor *l l*, to axis Y Y. The two axes are set in rotatory motion from the central telephone exchange by means of a battery P′ (Fig. 267), whose current can be reversed. This current is conveyed to the automatic switchboard (Fig. 266) by the wire *a*. When, for instance, a direct or positive current is sent, it acts upon a polarised relay R (Fig. 266), so as to close the circuit of a local battery P through the electro-

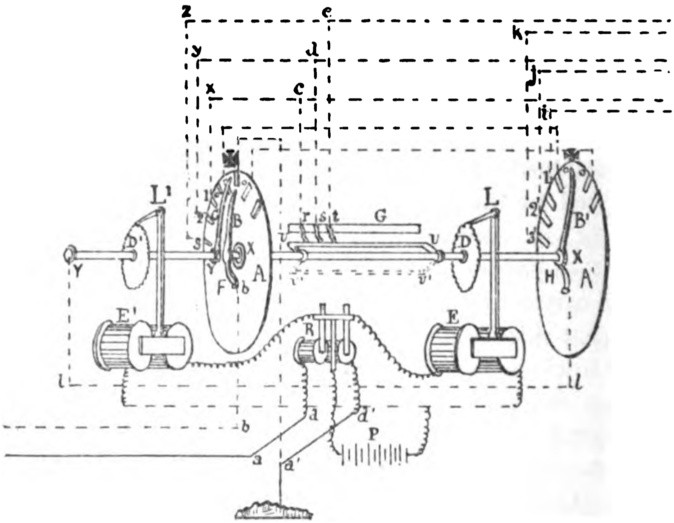


FIG. 266.

magnet E. When a current passes through this electro-magnet it attracts its armature, on which is mounted a lever L, which transmits the action to a ratchet wheel D on the axis X X, and this communicates its motion to the latter. If the current is of inverse sense, or negative, it acts on the same relay R in such a way as to close the circuit of the same local battery P through an electro-magnet E′, whose action is transmitted by the lever L′ to the axis Y Y.

These currents are sent either by a Morse key M, supplemented by a switch (Fig. 267) and an indicator showing the relative positions of needles B B′ and C at the distant automatic station, or by an automatic manipulator (shown in Fig. 269) provided with a Morse key M and clockwork, which causes a rigid needle to rotate. This latter can, by means of a pin, be arrested in any position on a graduated dial, whose divisions correspond

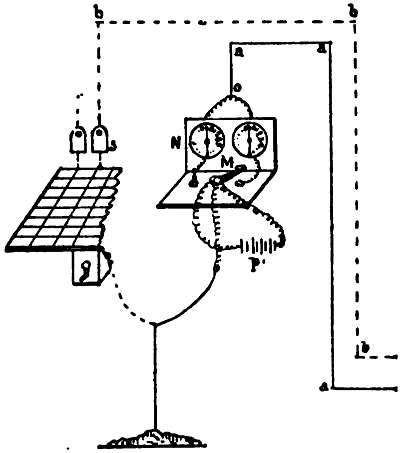


FIG. 267.

to those of the discs A A′. When the pin is removed and re-inserted in any position, and the key M depressed the movement of the clockwork transmits currents from the battery P equal in number to that of the divisions over which the needle has moved on the dial; and these currents, as already stated, bring about a similar displacement of the needles of the automatic switchboard at a distance.

218. In the arrangement shown by Figs. 266, 267 and 268, the subscribers' stations, which may be of any system

even with magnetic calls, are subject to no modification. There is only added to each a small two-way switch *m*, *m'*, *m''*, whose function will be easily understood by reference to Fig. 268. At No. 1 and No. 3, the switches *m'* and *m'''* close the circuit by the return wire, without going to earth; whilst at No. 2 the circuit terminates at earth.

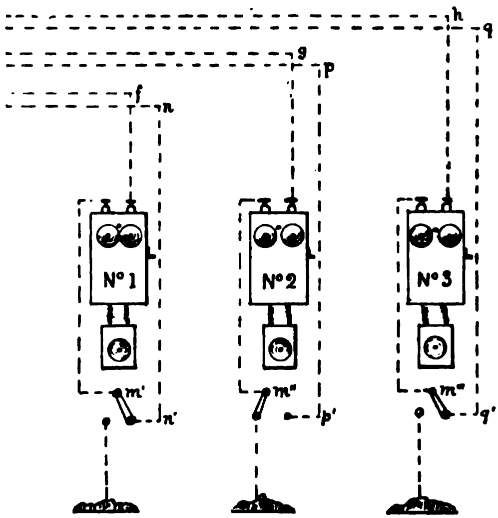


FIG. 268.

Before describing the manipulation of the apparatus, it should be mentioned that in addition to the contacts 1, 2, 3... the disc A carries three more contacts, marked +, *o* and *o* respectively. The former, on which the needle C stops when at rest, is connected to earth, and has only half the length of the contacts 1, 2, 3... so that it does not meet the needle B. The two other contacts, marked *o o*, are placed on either side of the former, are of half-length likewise, but are arranged in such a way that they can meet B only, and not C. These two contacts, *o o*, are connected each to a similar contact on disc A′; there is, however, no contact corresponding to + on the latter.

Let us now suppose that a subscriber (No. 2 for instance) wishes to ring up the central office. He turns the handle of his switch *m″* to the left (as indicated in the figure), and sends the call current. This latter, starting from earth, traverses the generator, follows the line wire through *g* as far as *d* (Fig. 266), and, the contact at 2 being open, passes through strip *s*, and the corresponding point of rod *v v*, and arrives at the axis X X. This latter is, by means of a friction-contact F, joined to the wire *b b b*, which is connected to a call bell at the central exchange, and thence goes to earth. The call having thus been received at the central station, the operator ascertains the name or the number of the calling subscriber; then by the means indicated above, he brings the needle B on the contact No. 2 of the disc A. At the same time the needle B′ will have moved to 2′ on disc A′, and the points of rod *v v* will have left the contact of the flexible strips *r*, *s*, *t*. From this moment the communication between the central office and subscriber No. 2 will be an exclusive one in favour of the latter. It will have been established, starting from the switchboard, by means of the wire *b b b*, the friction-contact F, needle B, the wire 2 *y d g*, and go to earth through switch *m′* after having traversed the instrument at No. 2 (Figs. 266 to 268).

Let us now suppose that subscriber No. 2 wants to speak to subscriber No. 3, who is connected with the same automatic switchboard. In describing the *modus* *operandi* in this case we shall at the same time show how the central station can call any subscriber whatever, as well as how the double connections for one and the same group of subscribers are made.

We take up the operation at the moment when, the call of No. 2 having been received at the central station, the number of this subscriber and that of the desired correspondent have been ascertained. The operator will now proceed to call the latter. This he effects by the means described; he moves the needles B and B′ on the contacts 3 and 3′ of the discs A and A′, and sends a call current into *b b b*. This current passes through the said line, spring F, needle B, line 3 *z e h*, to subscriber No. 3, and thence through switch *m‴* and the return wire, *q k* 3′, back to the central station (Figs. 266 to 268). From the point 3′, to which the needle B′ has been brought, the current follows this needle, the spring H, the conductor *l l*, the axis Y Y, and the needle C arrested by the contact +. This latter being connected to earth, the circuit is thus completed, and the call current sent into line *b b b* acts on the call bell of No. 3.

The subscriber No. 3 having answered the call, the current of battery P′ at the central station is reversed, and can now be used for actuating the needle C. This latter is thus brought on to contact 2 of disc A, and the circuit, instead of terminating at earth through the position of needle C on contact +, is now extended beyond this needle through the wire 2 *y d g*, and goes to earth through switch *m′*, after having passed through the instrument of subscriber No. 2.

When the clearing-out signal is received the central station brings the different parts of the apparatus back to their positions of rest.

There only now remains to explain the use of the contacts *o o* and *o′o′* on the discs A and A′. Their purpose is to control from a distance the position of B B′ and C. A reference to the diagrams will show that the different needles moving over these points cause in line *b b b* makes and breaks; so that, by placing a battery and a galvanometer on line *b b b*, these different changes can be verified, and the position of the needles controlled from a distance.

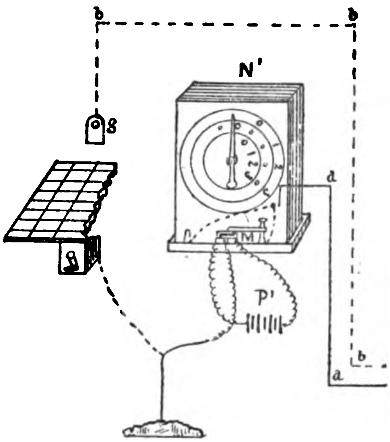


FIG. 269.

Second System.

219. This is a single wire system, and is represented in Figs. 269, 270, and 271.

The apparatus (Fig. 270) still contains the two axes, axis Y Y carrying needle C, and axis X X carrying only a single needle and the rod *v v*. The two axes are both connected to line *b b b* by F *b b* and Y *b′ b′*. There is also only one disc A carrying the contacts 1, 2, 3, ... to which are connected the subscribers' lines, and which are met by the needles B and C. There are likewise three supplementary divisions, +, *o o*, but there is no contact at point +, and the contacts *o o* are in direct connection with earth. The shunts on the subscribers' lines lead to the strips *r*, *s*, *t* of the transverse piece G.

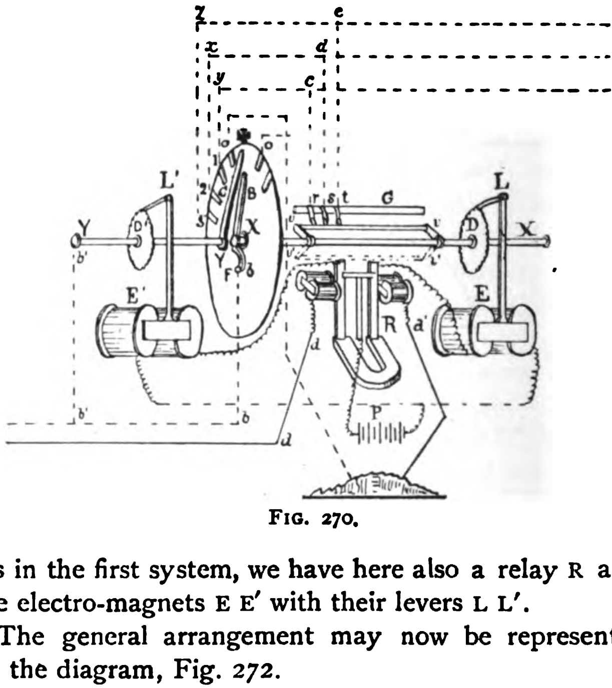


FIG. 270.

As in the first system, we have here also a relay R and the electro-magnets E E′ with their levers L L′.

The general arrangement may now be represented by the diagram, Fig. 272.

It will be seen that, when the apparatus is at rest, the subscribers' lines, without exception, branch off from line *b b b*, from the fact of their being connected with the rod *v v* and the axis X X. Neither of these offices, therefore, could send a call current to the central station, because, in practice, the line *b b b*, which connects the latter to the automatic switchboard A, is longer and, consequently, offers much more electrical resistance than the combined resistance of the lines A1, A2, A3, etc.

A new principle had, therefore, to be introduced for the single wire system, and it consists in the addition of

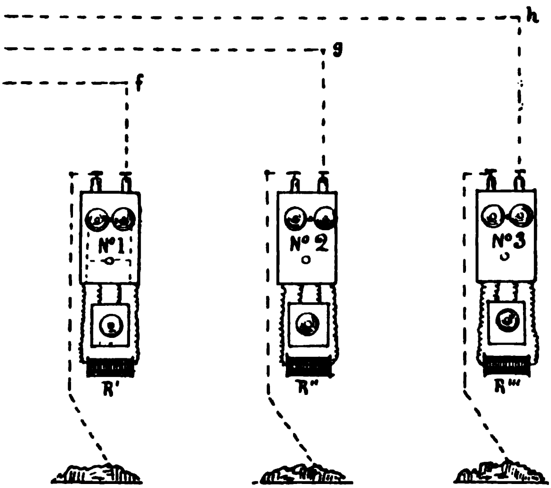


FIG. 271.

supplementary resistances, R′, R″, R‴ .... on the subscribers' lines. These resistances are so adjusted that a current sent from one of the stations, No. 3 for instance, and going by line 3A to the common point of connection, meets there in the auxiliary lines, A1, A2, A3, with a resistance high enough to allow a small portion of the current only to pass into each of the lines. The line *b b b*, on the other hand, which now has relatively a much lower resistance, will allow a sufficient quantity of current to pass to the central station to ring the call bell there, although the currents in the auxiliary lines will not be sufficiently strong to act on the calls at the other stations.

In order to obtain good practical results the resistances are connected in such a way that they can be short-circuited by simply pressing a button, whilst the subscriber sends his call current, and, likewise, that the unhooking of the telephone for the purpose of conversation removes them from the circuit.

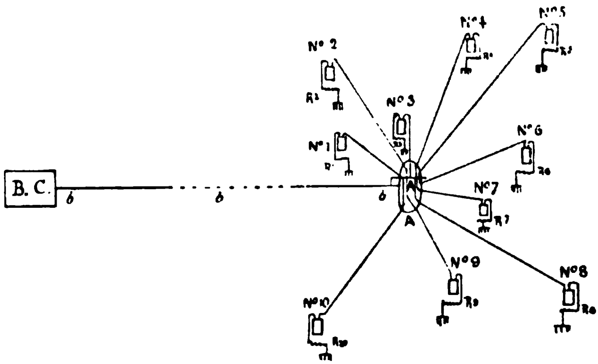


FIG. 272.

The working of the system will now be easily understood by reference to the figures.

Subscriber No. 2, for instance, wishes to call. He presses the call button, and in doing so short-circuits his resistance. The current passes through *g d s*, rod *v v*, axis X X, spring F, line *b b b*, call bell S, to the earth connection of the switchboard at the central station. The operator brings needle B on contact 2, the rod *v v* leaves the contact of the strips *r*, *s*, *t*, and the circuit is established through *b b b*, F B, and line 2 *x d g*.

If subscriber No. 2 wants No. 3, the operator at the central station calls this latter by bringing needle B on contact 3 and sending the call current through *b' b b*, F B and line 3 *z e h*, to post No 3. In this position the other lines are disconnected, and the call current, passing exclusively to line 3, is strong enough to overcome the resistance R'''. This is the mode of calling a subscriber in all cases. To complete the communication with No. 2, the current, as in the first system, is reversed at the central station, so as to make it act on axis Y Y, and to bring needle C on contact 2. The subscribers Nos. 2 and 3 will now be able to communicate, having short-circuited their respective resistances by unhooking their telephones, and the clearing-out signal can be given to the central station when their conversation is finished.

The contacts *o o* serve, as in the first system, to control from a distance the position of the needles by means of a galvanometer.

It must be remarked that the modifications produced in the electrical phenomena consist, not only in makes and breaks of the circuit, but also in very considerable variations of the latter's resistance. Thus the position of rest gives rise to a very strong deflection of the galvanometer, because it corresponds to a shunting of current through all the derived lines.

220. It should be noticed also that with either system no call can be made to the central station by the subscribers of a group as soon as one of the stations is in communication.

In the first system, the subscriber, who is made aware of this state of affairs by the fact of his call bell not being rung in answer to his call, can place himself into what may be called waiting attitude by turning the handle of his switch to the left. If now the operator at the central station, after having restored all the apparatus to their state of rest, sends a current into line, this current will act on the waiting subscriber's call bell, and thus inform him that the line is clear.

In the second system the same result can be obtained by the addition at each office of an annunciator-drop, by means of which, on the giving of the signal, the supplementary resistance is short-circuited. In this case, likewise, a current sent from the central station, after the apparatus has been restored to rest, will cause the drop to fall.

Finally, we may mention that M. Bartelous is now engaged with the final details of a system even more complete than the preceding ones. This system contains three or four wires between the central station and the automatic switchboard. Of these four wires one is the working line, the second is a call line, to which all the subscribers' offices are connected in a state of rest. As regards the communications, they are established by means of a third wire, or by means of the third and fourth wire. In the latter case two distinct communications can be established simultaneously. The details and sketches of this system have not yet been published.

M. Bartelous' automatic switchboard has been adopted by the Belgian Telephone Company. At Brussels, the length of the connecting lines with the central station is 7 kilometres, with a resistance of 350 ohms. Nineteen subscribers are grouped together, the supplementary resistance amounting to 2,000 ohms. With shorter distances and less resistance as many as twenty-five might be grouped together.

It is particularly applicable in outlying districts, where the number of subscribers is not sufficiently large to pay for the expense of an ordinary exchange, and for Sunday and night service in larger branch exchanges.

(b.)—*SINCLAIR'S AUTOMATIC SWITCHBOARD.*[1]

This instrument, designed by Mr. D. Sinclair, of the National Telephone Company, Glasgow, performs the same functions, viz:—those of switching any subscriber on the branch exchange, on which it is placed, into connection with any other subscriber on the same instrument, or with any other subscriber on the whole system, in a similar way.

A step-by-step sender is employed at a central exchange to transmit electric currents to the automatic instrument which is placed in the branch exchange, and each impulse passes through the coils of an electro-magnet or relay, which acts on the escapement of a train of wheels, and thereby intermittently turns a spindle on which a pointer is carried. In an instrument arranged to work six subscribers' lines—such as is illustrated—the pointer has seven stops in the revolution, and seven impulses from the central exchange are required to send the pointer once round, a stop being made at each of the seven points. At each of

[1] "Engineering," 18th February, 1887.

these points there is fitted a spring with a terminal, which is connected to a subscriber's line, and the

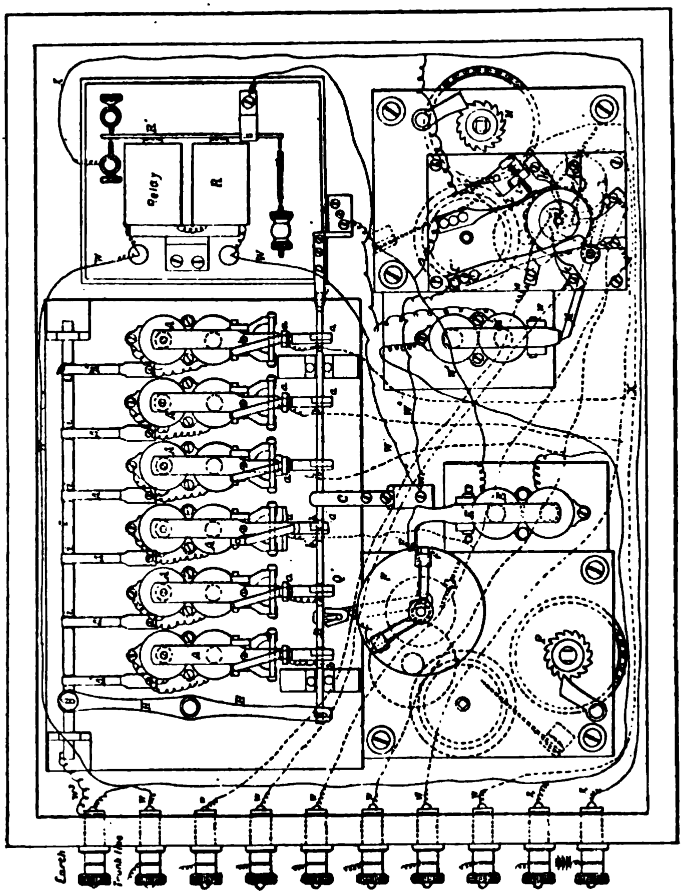


FIG. 273.

pointer on the spindle makes contact with the terminal opposite which it stops, as it is sent round by the impulses from the central exchange.

Figs. 273 and 274 show the apparatus in perspective and in section.

The wires from each subscriber's instrument are led to separate indicators A A, which are fitted in a row in front of a reciprocating notched bar, B. On the drops, *a*, *a* of the indicators are fitted projecting arms, *a'* *a'*, which, in the normal position of rest of the reciprocating bar, extend over inclined notches, *b' b'*, formed in the bar. When any subscriber rings up the exchange, the projecting arm *a'*, on the corresponding indicator drop *a*, falls into the notch *b*, and makes contact with the notched bar B, which is electrically connected with the central exchange. In this way the exchange operator is called up. The connection between the central exchange and the reciprocating bar B is made through the trunk wire W, the coils of a relay electro-magnet R, the wire W' W', and the terminal and spring C bearing on the bar B. At the same time the current passes through the notched bar B by means of a spring D and the wire w^1 to the coils of an electro-magnet E (similar to one of the subscriber's indicators), the armature E' of which is fitted with an escapement device F', arranged to set free the clockwork F, which acts through a lever G on the notched bar, and moves it in one direction to such an extent that the arm *a'* on the indicator drop is pressed into the inclined notch so as to remain in electrical contact with the bar, while the other notches are no longer directly under the arms on the remaining subscribers' drops. These drops now rest on or lie over small pieces of ebonite, so that these subscribers cannot for the time being ring up either the exchange, or each other.

The notched reciprocating bar is also connected by means of lever H to a rod *i i* on the opposite side of the indicators. This rod being connected to earth by the wire W^6, and serving as an earth wire for the subscribers' lines through the indicators, the movement of the notched bar traversing this earth rod to a certain extent, brings under the contact springs A^1 of each of the indicators a small piece of ebonite on the rod, whereby the earth connection is cut off; and, as the subscribers are unable to ring their call bells, they understand that the trunk wire is engaged. Connection between the central exchange and each subscriber on the branch exchange is made through a finger or pointer *j*, on a spindle I coming in contact with one of a series of springs *k k*, to which the subscribers are connected. The spindle I is rotated to such an extent as to bring the finger or pointer *j* into contact with the spring *k*, connected to any of the subscribers on the exchange by means of clockwork M and an escapement M^1, operated directly by an electro-magnet M^2, which is brought into action by the relay R when a current is sent along the main wire. The pointer is also employed to make a momentary contact between a spring L and a stud L′, thereby closing the circuit X through a local battery and through the electro-magnet E, which acts on the escapement F′, controlling the action of the clockwork F employed for actuating the notched reciprocating bar B, as previously mentioned. When the electro-magnet is thus momentarily brought into action, the escapement F′ is attracted and releases the clockwork F, so that it again moves the notched bar, but this time in the reverse direction, by which means the arm on the subscriber's indicator-drop is raised out of the inclined notch, and all the notches are again immediately brought under the projecting arms of the indicator-drops. This motion of the bar B is accompanied by a like motion of the rod *i i*, which, on being moved, brings every subscriber's line in connection with the earth wire, so that any subscriber may ring, and the same cycle of operations be repeated.

The return movement of the notched bar from the position which it assumes after a subscriber calls up the exchange is effected in the following way. The operator at the central exchange sends as many currents as may be requisite to bring the pointer round to the position in which it makes contact between the spring L and the stud L′, which cloes the local battery circuit X through the coils of the electro-magnet E, and thus actuates the escapement which releases the clockwork.

In order to effect communication between the central exchange attendants and the subscribers, the following mode of operating is resorted to:—The exchange operator sends a battery current through the trunk wire W, through the coils of the electro-magnet or relay R, to the reciprocating bar B, through the electro-magnet E, and thence to earth. In its passage the current closes the armature R′, of the relay, and then closes the local battery circuit X, and effects by means of the clockwork M one forward step of the pointer, from zero to first spring *k*, connected to the subscriber's wire W. At the same time, by acting on the armature of the electro-magnet E, the clockwork effects a movement of the reciprocating bar, which cuts off the earth connection from the subscribers and also from the electro-magnet acting on the clockwork. The succeeding current sent by the exchange operator passing through the relay R, closes the local circuit as before, actuating the spindle and finding its earth through the subscriber's spring *k* and wire W, with which the pointer is in contact. Each succeeding current acts in like manner until the pointer rests on the spring of the subscriber wanted. The exchange operator is then in direct communication

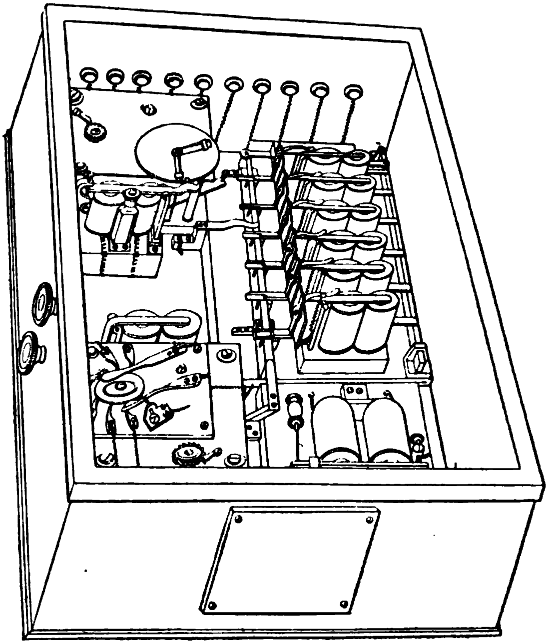


FIG. 274.

with the subscriber. When the conversation is at an end the operator again sends currents until the pointer reaches zero.

In making its last step to zero the pointer presses the spring to make contact, and closes the local battery circuit through the electro-magnet acting on the clock-work F, and thereby moves the bar B back to its normal position, when the subscribers will be connected to earth, and the exchange trunk line will find its earth through the relay R, the bar B, the spring D, and the electro-magnet E.

The wire W^4, from the spring C to spring C′, which is requisite to give the connection with the spring D, is disconnected from the reciprocating bar B B, and the connection thus given depends upon the position occupied by the pointer *j*. It should be noted that when the pointer is brought round so as to make connection between the exchange and the subscriber wanted a magneto current is used to ring up the subscriber, and this intermittent current does not actuate the relay.

Sinclair's apparatus has several points in common with Connolly & MacTighe's: in the latter a notched wheel is used instead of the notched reciprocating bar; an electro-magnetic escapement and clockwork, and relays, likewise form part of the instrument. It was exhibited at the Paris Electrical Exhibition of 1881.

(*c*.)—*ERICSSON AND CEDERGREN'S AUTOMATIC SWITCHBOARD.*

221. This switchboard is used by the Swedish Telephone Company. It is represented in the diagram, Fig. 275, is intended for five subscribers, and works entirely automatically at the spot where the subscribers' wires radiate off from the single line wire. Apart from accidents, it requires no attention beyond the occasional cleaning of the points of contact.

The apparatus consists of—

1. A dial V, whose centre is at *c*. The needle which moves over this dial is, for the sake of clearness,

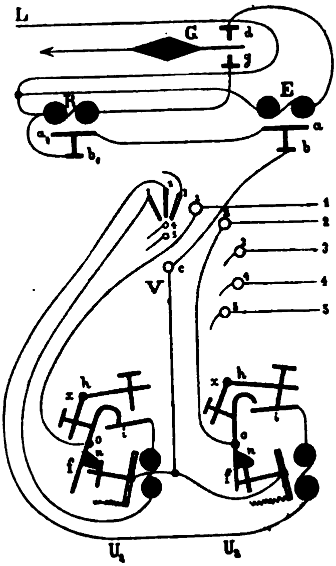


FIG. 275.

omitted from the diagram. In a vertical line above the centre *c* are five points of contact, 1—5, which, when the needle is in a position of rest (vertical), all make contact with it, and consequently also with point *c*. On the circumference of the dial are likewise five contacts, 1—5, connected with the subscribers' lines.

2. An electro-magnet E, whose two coils have a resistance of 200 ohms. When the armature *a* is

attracted, it leaves the stop *b* and breaks the circuit at that point.

3. An electro-magnet R, which is similar in every respect to the electro-magnet E.

4. A galvanometer G, whose coil has only 25 ohms resistance. The magnetised needle of this galvanometer is in permanent connection with earth, and by its oscillation to the right and left makes contact with the stops *d* or *g*.

5. Five polarised electro-magnets, of which two only, U_1 and U_2, are shown in the diagram, the three others being omitted. Three wires lead to each polarised electro-magnet, two coming from the points of the dial carrying the same numbers, and one coming from the axis *c* of the needle and connected with the armatures of all. The two coils of each electro-magnet have together a resistance of 1,750 ohms. The position of rest is indicated by U_1, the position of work by U_2. There is still a third position, of which we shall speak further on. *f* is a contact lever pivoted at *o*. At *n* is an insulated stop which arrests the armature in its position of rest and insulates it from the lever *f*, and which, when the apparatus is at work, prevents the return of the armature to its original position. A spring, not shown in the figure, places the lever *f* in its working position; *h* is another two-armed lever, whose axis is at *x*. The levers *h* of all the five polarised electro-magnets have the same common axis, so that when one of the levers *h* passes from position U_1 to that of U_2, the four other levers must follow the same movement.

The central station calls either of the five subscribers in the following way: To call, for instance, subscriber

No. 1, the operator at the central station sends a positive current into line. This current enters the automatic switch through L, traverses the indicator G, passes through $b_1 a_1$ *a b* to the centre *c* of the dial, and from thence into the needle which rests on the five contacts 1 to 5. From this point the current branches off through the five polarised electro-magnets to the different subscribers, where it goes to earth. The current being positive, so far from disturbing the position of rest of the armature of the electro-magnets U rather confirms it; nor can it ring the subscribers' bells, because these bells are only actuated by reversed currents, such as emanate from magnetos; this positive current therefore, in its whole course, only influences the needle of the galvanometer G. This needle is very heavy; it is composed of three rods of magnet steel, and is maintained in neutral position by a strong directing magnet and a brush of badger-hair rubbing against a steel rake. Its motions are, therefore, relatively slow, and in returning to its position of rest it is scarcely deflected beyond it, being gently arrested by the brush. Moreover, having reached the abutments *d* or *g*, it remains in contact with them for about one second. The positive current deflects it towards *d*, and by means of this contact a new route of much less resistance is opened to the current through the electro-magnet E to earth. The armature *a*, which is connected with a ratchet wheel of the needle of dial V, is attracted, and causes this needle to advance by one step, so that it comes to place itself against the point 1, which is in connection with the first subscriber.

Now the road is clear between the central station and the first subscriber, through L, b_1 a_1, *a b c*, and the needle of the dial; none of the electro-magnets are any longer in circuit. The central station and subscriber No. 1 can call one another by means of the magneto without disturbing anybody, for the galvanometer is not actuated by these reversed currents. The four remaining subscribers are disconnected and can neither disturb the established conversation nor overhear it.

If, instead of the first subscriber the central station wishes to call another—No. 4, for instance—the operator sends four positive currents into line, and the needle comes to place itself on point 4, which is in connection with the subscriber's wire of the same number.

As soon as the clearing-out signal has been given, the operator sends a negative current of about two to four seconds' duration. The needle G is deflected in the other direction and abuts against *g*, so that the current passes into the electro-magnet R, and thence to earth. At the moment when the armature a_1 of the electro-magnet leaves the stop b_1 the subscriber's line is broken, and the entire current passes through R. By the attraction of armature a_1 the ratchet wheel of the needle V is released, and this latter returns to its position of zero by means of a spring which has been wound up by the advance of the needle. Thus the whole apparatus returns to its position of rest.

In the calls of the subscribers by the central station, the polarised electro-magnets U take no part, their functions being confined to the subscribers calling the central station. Let us suppose that subscriber No. 1 wishes to call the central station: He rings as if he were the only subscriber on the line; the alternating currents pass through 1 into lever *f* of U_1, spring *i*, the coils of the electro-magnet, and through the combined contacts 1 to 5, and finally through *c b a* a_1 b_1 to line. It is true, these currents find, through the combined contacts 1 to 5, four other routes to the subscribers 2 to 4, but only during an excessively short time; for the armature of electro-magnet U_1 is immediately brought to the position indicated by U_2, and arrested in this position by the stop *n*. The entire connections are changed by this movement. The armature makes contact with lever *f*, and the contact of this latter with spring *i* is broken; the lever is pulled by the action of the spring, and, by doing so, repels the lever *h*, which lowers the spring *i*. All the five levers *h*, however, having common action, the others, too, have depressed the respective springs *i*; all the other electro-magnets are, therefore, out of circuit, and the current of subscriber 1, entering the armature through *f*, and going thence to needle V has only one route left, namely—the route to the central station, where it passes through an electro-magnet. The needle G does not move, and connection is made between the subscriber and the central station without needle V having left its position of rest. When the conversation is finished, the central station sends a negative current into line, which actuates the electro-magnet R. The armature a_1 being attracted, has not to bring back the needle V to zero, but restores the levers *h*, which are in the position U_2, to their position of rest, indicated by U_1, and the armature of U, under the action of the spring, thus takes up again its original position.

When a subscriber wishes to speak with another subscriber whose line branches off from the same automatic switch, if, for instance, No. 3 asks for No. 5, the central station, called by subscriber No. 3, sends five positive currents to line, and thus places needle V on 5. The two subscribers, No. 3 and No. 5, and the central station are now connected together. In order to restore the whole system to its state of rest, on the termination of the conversation the central station sends a negative current, and the armature of electro-magnet R now fulfils two functions: in the first place, it brings back the needle V to zero; and, secondly, it gives to the levers *h* the position of rest, indicated by U_1.

If less than five subscribers have to be connected with the central station, the terminals which are not utilised are connected to earth through an artificial resistance of 110 ohms.

(*d.*)—*OESTERREICH'S AUTOMATIC SWITCHBOARD.*[1]

222. The automatic station represented in Fig. 276 consists of the switch properly speaking, a polarised relay R′, and as many ordinary relays, R_1 R_2 R_3, as there are subscribers connected to the switch. The switch of Fig. 276 is arranged for three subscribers, whose lines are marked 1, 2, and 3. A battery, P, and a resistance, R, complete the arrangement. The switch, properly speaking is not visible in the diagram, but its functions will be understood from the following: It consists of a cylinder movable round a horizontal axis. On this cylinder, which is of insulating material, are eight rows of contact pieces, shown in plan projection at Y, with their respective spring plates, r^1 to r^{10}.

The cylinder is actuated from the central station by means of electric currents, which traverse the electro-

[1] "Journal Télégraphique," No 8, 1887.

magnet C, whose armature, ending in an escapement pushes the cylinder forward by one tooth at each closing of the circuit. Instead of causing the cylinder to rotate by means of electricity, this can be effected by a weight; in this case the electrical impulses only release the escapement wheel by one tooth. The weight, on

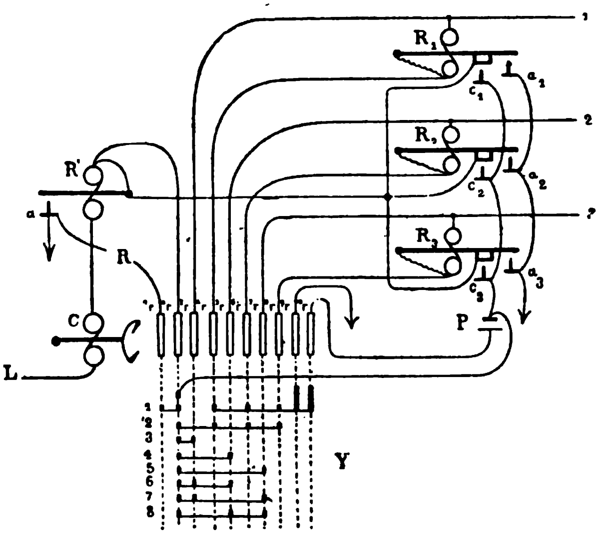


FIG. 276.

arriving at the bottom, closes the circuit of an alarm bell, which continues ringing until the attendant has wound up the weight.

The cylinder can take up eight different positions corresponding to the eight rows of contacts, 1—8. When the position of the cylinder is such that the contact pieces of row 1 touch the springs, there is electric connection between the springs r^1 and r^2, and between r^4, r^6, r^8, r^9, and r^{10}. When, by an electric current passing through electro-magnet C, the cylinder advances by one tooth, it is the second row of contacts which come to press against the ten plates r, and connection is made between the springs r^2, r^4, r^6, and r^8.

Thus, for each of the eight positions of the cylinder, the electric connections established thereby can easily be ascertained.

The switch is in its state of rest when the contacts of row I touch the springs. Each of the three subscribers can then call the central station without disturbing the others. If, for instance, subscriber 2 calls, the current takes the following path: Through 2 it traverses the relay R_2 (for in the direction of spring r^5 there is a break of contact), and through the springs r^6 and r^9 it reaches earth; but the passage of the current attracts the armature of relay R_2 and so opens to the current another route to earth through contact a_2. There is, at the same time, a second contact established through the movement of the armature; an insulated piece fixed to the armature abuts against c_2, and a current from battery P can pass through c_2, R^1 C, and line L, to the central station, and thence return through earth to P. This current has not the proper direction to move the armature of the polarised relay R^1, nor sufficient strength to actuate the relay C; it therefore has no other effect but to call the central station. This station sends a current strong enough to cause the cylinder to advance by one tooth, and thus position II. is established. The latter current passes through L, C, R^1, r^2, r^1, and an artificial resistance, R, to earth, the armature of the polarised relay R touches the stop *a*, and thus opens to the current a more direct route to earth. Position II. of the cylindrical switch having been obtained, the telephonic communication between the calling subscriber and the central station can commence.

In this position II. the other subscribers can take part in the conversation; they can also call, but this produces only a very short and faint click for the conversing subscribers, who from this fact know that another subscriber wants the central station. The three subscribers conversing at the time can then agree which two are to have the preference.

To establish communication through the central station with the subscriber of another line, the central station gives to the cylindrical switch the position III., if the calling subscriber is 1; position IV., if subscriber 2 has called; and position V. for a call made by subscriber 3.

In case a subscriber asks for another on the same wire, positions VI., VII., and VIII. are given. By means of VI., subscriber 1 is connected to 2; by means of VII., subscriber 1 with 3; and by means of VIII., subscriber 2 with 3. The current path in each special case is easily followed. In position VI. for instance, where subscriber 1 is connected with 2, the current arriving from 1 passes, without traversing the relay R_1, through spring r^3 to the springs r^2 and r^5; through r^5 the current arrives at subscriber 2, through r^2 it reaches the central station, which is connected up in such a way as to receive the clearing-out signal.

At the end of a conversation the central station operator always brings back the cylindrical switch to its original position, but he must make sure this position has actually been reached. For this purpose there is between the contact rows 8 and 1 a contact, which corresponds to spring r^3, and is connected with one pole of battery P, and the two last contacts of row 1 are prolonged towards row 8. When the cylinder passes from position VIII. to position I., spring r^3 for one moment glides over the contact, which is connected to one pole of battery P, whilst the other pole is connected through springs r^9 and r^{10} to earth; a momentary current therefore reaches the central station, and there gives the signal on a galvanometer, indicating that the cylinder has been restored to its original position.

If the operator at the central station wishes to call a subscriber, he has only to move the cylinder of the automatic switch to the required position. For instance, when subscriber 3 calls, the operator moves the cylinder until row 5 of the contacts at Y arrives beneath the springs *r*.

CHAPTER XXVII.

SEVERAL SUBSCRIBERS PLACED ON ONE CIRCUIT (III.).

223. IN the preceding descriptions of automatic switchboards a number of stations were served by one line wire, and an automatic apparatus was installed at the point where the branch wires leading to a limited number of subscribers radiated off from the single line wire. This system, which we may call *radial*, has the one great drawback, that it can with advantage be applied only to a limited number of subscribers living within a short distance of each other. The automatic switchboard, if constructed for a large number of subscribers, would become exceedingly complicated, expensive, and liable to get out of order, and the advantages of the system, which consist mainly in doing away with a paid official, would thereby disappear.

It is, therefore, in many cases, more convenient to connect the subscribers by one wire, in *series*, after the manner of telegraph stations.

Various solutions of this problem have been proposed.

Mr. Elsasser[1] has modified Wittmer and Wetzer's individual call system for telegraph offices[2] in such a way that it adapts itself to telephone stations arranged on one and the same wire.

[1] "Electrotechnische Zeitschrift," vol. iv., p. 161.

[2] "Zeitschrift für Angewandte Elektricitätslehre," vol. iii., p. 439.

224. Professor Zetsche[1] has further modified this arrangement, and has, besides, published two other solutions for the series connection of subscribers, which are of interest.

In the first of those systems each subscriber's station is provided, in addition to the usual telephonic apparatus, with two polarised relays, a call-bell with local battery, a call button, a line battery and a rheostat. The central station must be able to send at will currents of different strengths, as many different currents as there are stations placed on the line. The current of unit strength only actuates the first relay of the first station; the current of double strength the second relay of the first station and the first relay of the second station, and so on; so that for station n a current n times stronger than the first one is required, and this current actuates the first relay of station n and both the relays of the preceding stations. The attraction of the armature of the first relay of any station breaks the line leading to the following stations, and closes the local circuit of the call-bell, which rings until the telephone is unhooked. The attraction of the armatures of both relays opens a route through the station to the exclusion of the telephonic apparatus; the uncalled stations are thus put out of circuit during the conversation of the called station. At the end of the conversation the central station sends a current to line of force n, and of opposite direction, which restores all the armatures to their state of rest. When one of the subscribers wishes to call the central station he has only to press his call-button and a current which does not influence the relays, and consequently cannot interfere with

[1] "Electrotechnische Zeitschrift," vol. iv., p. 257.

the other subscribers' stations, causes the annunciator of the central station to drop.

The second arrangement only requires one polarised relay for each subscriber's station. All the electromagnets and call-bells of the subscribers are, in the state of rest, placed in the line circuit; if, therefore, the central station calls (by currents which do not influence the relay armatures), all the call-bells ring at the same time, and a special signal is required for each subscriber, as in telegraphy. The operator at the central station, by unhooking his telephone, excludes all subscribers situated beyond the central station, but he must also exclude those subscribers who are situated between the central station and the called station, and this he does by sending a current to line which influences the armatures of the polarised relays. At the end of the conversation the relays are of course brought back to their original positions.

225. Hartmann and Braun, of Bockenheim, have constructed an apparatus which seems to present a more complete solution of the problem. The apparatus readily adapts itself to the different telephonic systems with magneto or battery call. Externally it has the appearance of a magneto call-box. On its front, at the bottom, is the mouthpiece of the microphone, and higher up are two dials, the one on the left with a handle and carrying the inscriptions, "put to rest" (*abstellen*), "put on call" (*einstellen*), "call" (*aurufen*), and "conversation" (*sprechen*); the one on the right with a needle, and as many numbers on the periphery as there are stations on the line. The telephone receivers, the handle of the magneto and the call-bell complete the external fittings.

Within the box the most important part of the system is an axis carrying the needle of the right-hand dial mentioned above. This axis, which fulfils several functions, is represented in Fig. 277:—C is the outside dial, whose needle is at zero in a state of rest, and can occupy five other positions corresponding to five subscribers placed on the line. Behind the cylinder *a* is a second cylinder, *c*, which can, by means of lever *d*, be moved forward or backward on the axis. On the axis is a small cam *e*, which, in a state of rest, fits exactly into a hollow of cylinder *c*. Still further behind is a ratchet wheel *r*, with an escapement *t*, and finally, a spring plate *p* presses on the axis and makes contact with it. On the cylinder *a* is fixed an insulating segment, *n*, which at each station will be found on a different part of the cylinder. At the station No. 1 the segment is placed in such a way that it is beneath the spring *b* when the needle is on the number 1; at the station No. 2 this will be the case when the needle is on 2, and so on.

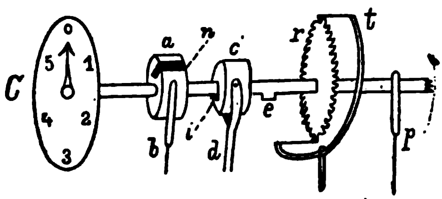


FIG. 277.

When all the needles are upon zero, the line circuit at each subscriber's station passes through spring *b*, cylinder *a*, the axis, the spring *p*, and a polarised electro-magnet, whose armature is attached to the escapement *t*. Nothing, therefore, is placed in circuit except these electro-magnets at the several stations. If, now, currents of the right description are sent to line, these currents actuate the armatures of the polarised electro-magnets, the escapement *t* enters into action.

the escapement wheel *r* begins to turn, and with it the dial needle, which passes successively over the different numbers on the dial. Each station, as mentioned above, has a magneto to produce these alternating currents, but this magneto is not placed in circuit. If a subscriber wishes to call another subscriber or the central station, he must place the handle of the left-hand dial to "put on call." By this movement of the handle the lever *d* is pushed to the right, and the cylinder *c* passes over cam *e*; this latter then appears on the left of cylinder *c*, and the axis is now again free. If the subscriber now turns his magneto, he moves the needles of all the subscribers, his own included. To call, for instance, subscriber 4, he turns the handle of the magneto until the needle has arrived at number 4. At station 4, the insulating segment *n* of the cylinder *a* has now arrived under the spring *b*, and the current can no longer pass through the axis, but traverses the electro-magnet of a call-bell. The calling subscriber then places the handle of the left-hand dial on "call," and hereby changes the alternating currents of the magneto into a direct current, which cannot influence the polarised relays, but rings the call-bell of subscriber 4. By unhooking their telephones the two subscribers can now converse, since by the movement of the hook the micro-telephone is placed in circuit instead of the call-bell; but the other subscribers cannot overhear the conversation, because their telephone is not in circuit, and because cylinder *c* cannot pass to the other side of cam *e*, since this latter no longer corresponds to the gap in cylinder *c*.

The conversation being finished, the needle is brought back to zero, and the cylinder *c* to its position of rest. The central station is treated like any other subscriber, and proceeds to call in the same way. If the subscriber forgets to bring his needle back to zero, the central station can do it for him.

226. Mr. Johnston Stephen applies to his system the principle of pendulums of different length, which Bizot had at one time proposed for the individual call of telegraph stations. In Fig. 278 we give a diagram of this system, showing the complete arrangement of a subscriber's station, placed with a certain number of similar stations on a single wire :—T_1 is the micro-telephonic apparatus,

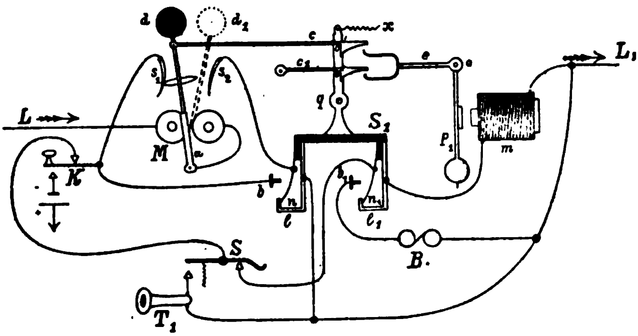


FIG. 278.

K the call-button, and B the call-bell; M is a polarised electro-magnet, whose armature can take up two positions: the position of rest, *d*, when a positive current circulates through line L L_1, in the direction of the arrows, and the position d_1, when this current is of opposite direction; S_1 is a lever, the two arms l and l_1 of which are insulated from one another; the insulated springs n and n_1 make contact with them in a state of rest. The axis of lever S_1 is at q, and its upper arm is pulled to the right by the spiral spring x, but kept in a vertical position by the two hooks c and c_1. The pendulum p_1 has a different length, and therefore a different rate of vibration, at each subscriber's station; it oscillates about the point *o*, and carries the forked lever *e* along with it; *m* is an ordinary electro-magnet.

To understand the working of this apparatus, we will first of all explain the call of the central station by a subscriber, and the mode of connecting this subscriber with another placed on the same or another wire. Six different stages may be noted in this operation.

1st stage.—The subscriber calls the central station (situated on the left of Fig. 278) by pressing call-button K. The current passes through s_1, *a*, and electro-magnet M, into line L, and returns through earth; in the subscriber's stations, which are between the calling and the central station, the current traverses the electro-magnets *m* and M, but only produces a very slight oscillation of the pendulum *p*. It cannot alter the position of the armature *a*, because it has not the proper direction. The communication between the central station and the subscribers situated on the right of Fig. 278 is interrupted so long as the button K is depressed.

2nd stage.—The subscriber unhooks his telephone and informs the central station of the subscriber's number with whom he wants to speak; after this he again suspends his telephone.

3rd stage.—The operator at the central station singles out the called subscriber. For this purpose he has a sort of metronome to which he can impart the rate of oscillation of the pendulum of any subscriber. This metronome, in performing its oscillations, sends positive currents to line, which do not affect the armatures *a*, but influence all the pendulums *p*; that one only of the pendulums, however, whose rate of oscillation corresponds to that of the currents, gradually attains sufficient amplitude to raise the hooks c and c_1, thereby causing the lever S_1, in its lower part, to incline to the left. The intermittent current from the central station passes now to the station thus singled out through M, a, s_1, K, S, n_1, b_1, and call-bell B.

4th stage.—The called subscriber unhooks his telephone, and is informed by the central station that a certain other subscriber wishes to speak with him. After this communication the telephone is again suspended.

5th stage.—The operator at the central station singles out the calling subscriber by the same method he has employed in the third stage.

6th stage.—The central station sends a negative current to line (or to the lines if the calling and the called subscribers are on different lines). All the armatures a hereby take up the position d_1, contact is made with spring s_2, and both at the calling and called stations the hook c again grips the upper arm of the double lever S_1.

Through this movement of the armature a, the disc d becomes visible, and indicates at all the stations that the line or lines are engaged. At the calling and called stations the call-bell B begins to ring, and at all the other subscribers' stations the current passes through M, a, s_2, n, and consequently the telephone T, as well as the button K, are put out of circuit, and it is impossible for any of these subscribers either to interfere with the conversing subscribers or to overhear their conversation.

When the two subscribers have finished their conversation, one of them sends, by means of button K, a negative current to the central station, thus informing the operator that he can restore the line or lines to the state of rest. The operator thereupon sends a positive current to line, which brings back all the armatures *a* to the position indicated in Fig. 278. At the stations of the subscribers who have been in communication, the hook *c* at the same time brings back the lever S_1 to the position of rest indicated in the figure.

227. An individual call system, devised by Messrs. Brown & Saunders, has been found very efficient in England. It is based upon the principle of the pendulum, as in the case of Mr. Johnston Stephen's apparatus.

Each signaller consists of two pendulums, the bob of the inner being fixed, and the rod attached to the armature of an electro-magnet. The outer pendulum has an adjustable bob sliding on the rod, which is graduated, and is arranged to send two currents for each complete vibration. The inner pendulum responds only to vibrations the rate of which corresponds with its adjustment. When it attains its full amplitude it opens the circuit of the call-bell, so that the line currents flow through it, and cause it to ring.

The system is applied in order to call only the office required; the bells at the other offices are not actuated.

228. A very simple and efficient system, which provides for absolute secrecy in communication between any two offices on a circuit, is in use by the British Post Office.

Each office is provided with a complete Gower-Bell-telephone (§ 35) with specially-arranged connections, a relay, and an electro-magnetic switch. The latter instrument is actually a relay, with two levers actuated simultaneously, and moving between independent contacts.

The battery for each office, where six offices are on the circuit, consists of twenty-four Leclanché cells, and these are so arranged that the current is always in the same direction. In the calling circuit at each office is placed a resistance of 450ω to reduce the calling current.

In the normal condition the coils of both relay and electro-magnetic switch are in circuit at each office. The relay local circuit is for ringing the call-bell, and the electro-magnetic switch normally places the telephone instrument in circuit, and, when the armatures are attracted, nothing but the coils of the switch can be in circuit. The connections of the telephone are such that on removing the tubes for speaking, a current is sent to line from the calling battery without the 450ω resistance in circuit. Pre-arranged signals are used for calling each office.

If, now, in the normal condition any subscriber depresses the press-button of his telephone, the reduced currents from the calling battery pass to line, and actuate the relay at each office. The electro-magnetic switches are adjusted so as not to be actuated by the ringing current.

After replying, the required correspondent removes the tubes from the switch rests, and so also does the caller; and, consequently, a current due to the full force of forty-eight cells is placed on the line. This current (more than double the ringing current) actuates the electro-magnetic switches at every office except those from which the current emanates, and so cuts all out of circuit. It is thus absolutely impossible for a third party to intervene, as the first two who lift the telephone tubes at once cut out all other offices.

On the tubes being replaced in the rests, the normal condition of the circuit is automatically restored.

An intermediate switch (§ 119) can also be provided at any office, so that the circuit may be divided at that point, and any two offices on each side of the switch can communicate simultaneously.

CHAPTER XXVIII.

APPLICATION OF THE TELEPHONE TO THE TELEGRAPH SERVICE.

229. THE credit of having utilised the extreme simplicity of this application belongs to the Administration of the German telegraphs, and there are at the present moment more than 4,000 telegraph stations in Germany making use of the telephone. No other corporation, either private or public, can boast of a similar development of telephony in this direction. The fears which were expressed at one time, that the extension of telephony must necessarily injure telegraphy, have been completely set at rest by this intimate fusion of the two services, and it has been found that the two supplement each other. In Germany the telephone is paramount for short distances, where the telegraph cannot compete with it; but as soon as the distances increase the value of the telephone is diminished, and it is finally the telegraph which exerts its uncontested claim. On the other hand, the telephone, combined with the telegraph, can penetrate into localities which are either too limited in size or too poor to support a telegraph station properly speaking. The installation of a telephone station is very simple and very inexpensive, the manipulation of the apparatus does not require any lengthened apprenticeship, and a telephone station can therefore be

established under much more favourable conditions than a telegraph office. In Switzerland, for instance, the only country besides Germany where the above application has been extensively adopted, any commune that wishes to be connected to the nearest telegraph station by a telephone line has to bear half the cost of construction of this line; it has, besides, to provide an office, to pay for the heating and lighting of the same, and to appoint and pay the officials. All the remainder, the installation and keeping in repair of the apparatus and of the line, and the whole of the expenses of the transmitting station, are borne by the central administration.

In England the A B C instrument, which requires practically no attention, is worked entirely by magneto currents, calls for very little skill on the part of the operator, and needs no privacy or silence, has so far held its place as the instrument for unimportant local circuits.

The combination of a telephone line with a telegraph office is most simple. Telephone and telegraph are independent of one another, and the oral message has only to be reproduced on a sheet of paper, and this document will serve as an original telegram for telegraphic transmission, and *vice versâ*. The telephone, however, requires a private room, and cannot be fixed in an open shop.

230. Sometimes a special line for the telephone station can be dispensed with, and the latter is placed in circuit on a telegraph wire. This arrangement is usually adopted where the telephone station lies on the route of the telegraph wire, and where telegrams are not too numerous. The call system in use in Switzerland allows of this interpolation without much difficulty, and we give, in Fig. 279, a diagram of such an

installation :—L L_1 is the telegraph wire, A the telegraph office, by the help of which the communications from the telephone station, B, are transmitted on the telegraph network, and *vice versâ ;* M is the Morse apparatus, T the key, and *p* the battery. The micro-telephonic system of each station is, for the sake of simplicity, represented by the telephone *t; c* and c_1 are switches for putting on earth when telephoning between A and B; G are the magnetos; *s* and s_1 alternating current call-bells; *b* the needle galvanometer of the telephone station. When the line L L_1 is being used for telegraphy, the earth connection is broken at *c* and c_1,

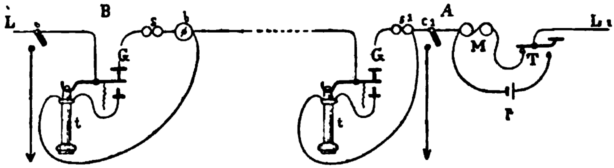


FIG. 279.

the telegraphic currents pass through the call-bells *s* and s_1, but do not actuate them, because they are not alternating. The direction of these telegraphic currents must be such as to strengthen the permanent magnets of these call-bells, not to weaken them. The magnetos, G, are, as usual, out of the line circuit when not in action. If the station B wishes to transmit telephonically a telegram to A, the operator first ascertains whether the needle *b* is at rest; that is to say, whether the line is free. If such is the case, he establishes the earth connection at *c* and rings. The call-bells *s* and s_1 begin to ring, and the telegraph offices on the right of B hear a feeble click of the armature of their receiver, which indicates the nature of the call. Station A, after having established earth connection at c_1, replies by means of the magneto, and the conversation can commence without any possibility of disturbance on the part of the telegraph stations. During all this time the line L L_1 can be utilised by the telegraph on the left of L, as far as the last office, and on the right of L_1, as far as A. The same arrangement can also serve when the telegraph line is worked by the continuous current system.

231. Another arrangement for working telephone and telegraph stations placed on one wire with continuous currents has been suggested by M. Zetsche.[1] When there are telephone stations on either side of the telegraph office which serves as an intermediary, it is above all things necessary to avoid currents which might weaken the magnetisation of the telephone.

Fig. 280 represents the telegraph office serving as an intermediary between the telephone stations placed on the lines L_1 L_2, on the right and left :—A is the Morse apparatus, M the key, *p* the battery, T the micro-telephonic apparatus, C a plug-switchboard with 5 strips, 4 of which are cut in the middle. As a rule, the plugs are inserted in the plug-holes 1, 3, 5 and 7, the current circulates in the direction of the arrows and strengthens the magnet of the telephone.

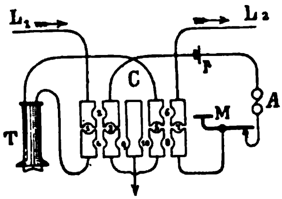


FIG. 280.

The telephone is placed in the line circuit, so that the

[1] "Electrotechnische Zeitschrift," vol. v., p. 211.

telephone stations may be able to call. In order to telephone with a station on the left of the intermediary office, an additional plug is inserted in either of the two plug-holes 9 or 10. The line L_2 is then independent of the line L_1, and the direction of the current is not altered. If, on the contrary, the telephone T has to enter into communication with a telephone station placed on line L, the plugs must be inserted in the plug-holes 2, 4, 6, and 8, and in 9 or 10.

The direction of the current in the telephone will remain the same in this case also. The telephone can also be put out of circuit by inserting plugs in the plug-holes 2, 4, 5, and 7, or in 2 and 7 only.

CHAPTER XXIX.

THE TELEPHONE AS A MILITARY INSTRUMENT.

232. THE use of the telephone in military operations is not so extensive as might at first sight appear likely. Indeed, when the conditions under which it is likely to be required in the field are carefully considered, several serious objections to its employment for transmitting articulate speech to any distance at once suggest themselves.

It is, of course, highly advantageous to an army to have the power of transmitting intelligence rapidly between its various divisions, outposts, wings, advanced and rear guards, etc., but the intelligence so transmitted must be absolutely correct, and the consequences of a mistake in the purport of a message may be so disastrous as to outweight any advantage due to rapid transmission.

It is the invariable rule in the British army that all important orders must be delivered in writing, and numerous instances are on record of fatal blunders which can be directly traced to a mistaken comprehension of verbal orders.

Now an order transmitted by telephone is worse than a verbal order delivered from one officer to another, since it is probably transmitted verbally between two clerks, who have no comprehension of its meaning and scope, and by means of a mechanism which, though a marvellous triumph of ingenuity, is far less efficient than the human voice addressed directly to the human ear.

Instances of the inaccurate transmission of telephonic messages are probably within the experience of all habitual users of the instrument; and there is a well-known incident which happened on a military line, luckily in peace time, when some intelligence as to the whereabouts of a submarine mine case at the Needles was received as an urgent demand for a case of needles.

In assessing the probable frequency of mistakes in transmission in the field, the adverse environment of the operators at the two ends of the line should be considered. It is difficult to determine whether the banging of cannon and rattle of musketry would be more distressing at the sending or at the receiving end of a circuit. No doubt they would be reproduced by the transmitters with too much fidelity. When to this is added the effect of the presence of numerous superior, but probably highly excited, staff officers, demanding urgency for their respective messages, the condition of the nerves of the unfortunate operator may be faintly imagined. *Illi robur et aes triplex*, indeed, if he keeps his head.

Another objection is the noise and publicity inseparable from the act of transmission. A general may require to send very important intelligence, but does not as a rule, care to have it slowly and distinctly shouted by the stentorian lungs of an ordinary soldier; while at the outposts in contact with the enemy the procedure would be clearly inadmissible. Still, although telephony proper cannot be considered generally suitable for the transmission of military messages, it has its own sphere of utility.

233. In standing camps, and even in temporary ones, not in the immediate presence of the enemy, there is vast scope for its employment in carrying out the routine business of the camp, promulgating orders, requisitions, etc. The amount of correspondence of this sort in a large camp is very considerable, entailing, where the use of the telephone is not resorted to, the constant employment of a large number of orderlies, and the loss of much time between the asking the simplest question—*e.g.*, the number of rations required by a certain regiment—and the receipt of the answer.

All this kind of business is admirably performed by the telephone. No definite system of working has yet been inaugurated, but it is probable that a regular exchange office will be established under the management of the Telegraph Battalion of Royal Engineers, in whose charge will be the necessary equipment. Each corps and department will have its own instruments and sufficient line, and will be responsible for installing its own circuit. The system can by this means be got into working order almost as soon as the tents are pitched.

An instructional exchange system has been working for some time at Chatham for the training of the clerks of the Telegraph Battalion, and is found a great convenience.

234. The principal use of the telephone in military operations is, however, as a telegraphic receiver.

As soon as telephones were procurable, efforts were directed to employ for military telegraphic purposes an instrument in which the feeblest currents could produce an audible signal.

At first the telephone was used to receive currents sent by a Morse key in the usual way, but difficulties were experienced with this. The sounds produced by the make and break of the current were so similar that there was a tendency on the part of the clerks to read the signals reversed; also when any Morse circuits were being worked in the vicinity the induced signals caused interference.

To obviate these defects a system of sending intermittent currents was introduced with great advantage. The intermittent currents produce a musical note in

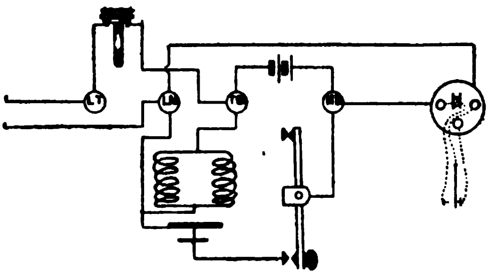


FIG. 281.

the telephone as a signal, and this cannot be read reversed or be interfered with by any ordinary induced current. Further, greatly increased sensitiveness was attained with less expenditure of battery power.

This system was practically tried by Captain Cardew, R.E., in 1881. The arrangement then adopted differs but slightly from that used in the latest pattern of instruments shown in Fig. 281.

The current is produced from a few battery cells, and passes through the coils of an electro-magnet placed in derived circuit with the line. This magnet attracts an armature mounted on a spring, which as it moves breaks the battery circuit, falls back and re-establishes it again, and so on, exactly as an ordinary chattering bell, except that the moment of inertia is much less, and the vibrations consequently more rapid, sufficiently so, in fact, to produce a musical note.

This electro-magnet, with its vibrating armature, is employed at the sending end of the line to transform the ordinary battery current into a pulsating current, capable of producing a musical note in the telephone; the signalling being effected with an ordinary Morse key.

The telephone on which the signals are received is inserted in the line and not on the back contact of the key, which is the usual Morse connection. The reason for this is that the telephone at the sending end of the circuit performs the office of the usual galvanometer, and informs the clerk that his signals are going out to line.

It will be observed that the current through the vibrating transmitter is practically unaffected by the state of the line, even if broken or very leaky, since the resistance of the magnet is only 10 ohms. This is of great utility, as signalling has frequently been carried on through broken wires, the ends making more or less earth, and also through wires in contact with earth throughout. Naturally the current to line in the latter case is greatly increased, and the work tells on the battery. It will also be observed that the "extra currents" in the transmitter increase the signal to line.

In the latest pattern of instruments the connections have been modified to enable a form of microphone to be used for speaking when required, the magnet coil acting as an induction coil. No switching is necessary with this use of the microphone, except a contact-making switch for the microphone itself, which is closed by the action of the hand grasping the handle of the instrument.

All messages sent by the clerks are, however, keyed in Morse characters and read by ear, speaking being employed only for direct communication between officers.

235. This vibrating system has been used with great advantage in all our recent wars, including the various Egyptian expeditions, and that to Bechuanaland, and it is now permanently adopted on the Egyptian Telegraphs. Its principal use has been for working through hastily constructed and faulty lines. All the messages from the field of Tel-el-Kebir were sent by it; and in the Nile Expedition its use on several occasions enabled very important work to be got through portions of the long line which were unworkable by ordinary instruments through faults. It has also been worked successfully through considerable lengths of bare wire laid on the ground and absolutely buried in places.

Although very useful in field telegraphy, this vibrating system is not suitable for general work on the permanent telegraphs of the country, for the following reasons:—

1. The note, or "buzz," is more fatiguing to the reader than the ordinary Morse sound signals, at any rate, to clerks used to the latter.

2. It is taken up by induction on parallel wires, causing interference.

3. It is much enfeebled by all kinds of induction. Current induction from parallel wires, magnetic induction in passing through electro-magnets, and static induction on long lines, and especially on underground or submarine circuits.

It was, however, extensively utilised and did good service on the postal telegraphs in getting through on the broken down wires after the great snowstorm of Christmas, 1886.

The advantages of the system for field work may be thus summed up :—

1. Its great sensitiveness, enabling communication to be effected through faulty lines, uninsulated wires laid on the ground, very bad joints, earths, etc.

2. The great saving of battery power effected by its use : 10 cells are the maximum that are ever used with it, and it works with even one cell; also the current, being vibratory, has little effect in polarising the battery. Of course, when the microphone is used, there is a greater expenditure of battery power, but this is not an essential part of the system.

3. The fact that the telephone as a receiving instrument never requires adjustment; this frequently saves much time in rapidly running out a line and getting into communication.

4. Speech may be resorted to when desired without change of connections or complication of instruments.

5. The note, or "buzzing" signals, are much more easily picked up by signallers trained to read flag and lamp signals, than are those of Morse instruments.

EMPLOYMENT OF THE TELEPHONE AT RIFLE PRACTICE.[1]

236. Rifle practice, as carried on in Germany, is intended to give the soldier an opportunity not only of improving his shooting, but also of becoming acquainted with the tactics of real warfare. For this purpose a

[1] "Electrotechnische Zeitschrift," No. 8, 1881.

whole company fires with ball cartridges at a number of targets representing the enemy.

To reproduce an image of the appearance or disappearance of the enemy in the field, these targets are made movable, and are moreover provided with percussion fuzes, which are ignited by match-cords. The latter contrivance, of course, represents the enemy returning the fire, and thus completes the image of a real fight.

Care must be taken to insure simultaneous action as regards the appearance or disappearance of the targets, which may be placed at the most varied distances, so as to produce a faithful image of the enemy's tactics; and it is also necessary that the moment of appearance or disappearance of the targets, as well as their entire manipulation, should depend upon the judgment of the officer in command of the practising company. A means of communication must therefore be provided between the officer in command and the men manipulating the targets.

It has been found, after various experiments with other apparatus, such as mirror signals, telegraphs, etc., that the telephone is admirably adapted to this purpose, and Lieutenant von Laffert has fitted up the necessary apparatus in the following way:—The transmitter and receiver are the Siemens' telephone, with special call trumpet (§ 30); the metallic circuit consists of four copper wires of ·8 mm. diameter, insulated with cotton yarn and indiarubber twisted together, and finally protected by a braiding of waxed cotton yarn; 500 m. of this cable are wound on a portable reel of the following construction:—

On each side of a hollow tin plate cylinder, ·4 m. length and ·12 m. diameter, is screwed a strong wooden disc of ·32 m. diameter. The interior of the hollow cylinder is divided by a partition into two equal parts, each of which serves for the reception of a telephone enclosed in a tin case. On both sides of the reel a movable handle is fitted, and on the extremity of one of these handles a crank can be fitted for winding up the cable. The surface of the hollow cylinder is perforated by a small hole close to the partition, as a passage for the interior extremity of the cable. To one of the wooden discs, close to a perforation for the passage of the second (exterior) extremity of the cable, is screwed a pin for fastening this latter.

One end of the cable of 500 m. length is inserted in the hole of the hollow cylinder, to a distance of about 2 m., and there held fast by a knot. The cable is then wound upon the cylinder, and the exterior end made fast to the pin just mentioned. The reel thus fitted up can be carried by one man, by the help of a leather strap fastened to a lug on either wooden disc.

One of the telephones is fastened to one end of the cable penetrating into the interior of the hollow cylinder. This side of the reel is marked by the letter E (end), the opposite side by the letter A (*Anfang*, German for beginning).

To lay the cable, the leather strap is removed, the tin case pulled out of the cylinder on the side marked A, the telephone taken out from the case, the handles fixed to the discs, the exterior extremity of the cable untied from the pin, and fastened to some fixed object.

One man establishes the sending station by connecting the telephone to the line, etc., while two other men, one with his right, the other with his left hand, lay hold of the reel and march quickly towards the locality selected for the receiving station, or for the junction with a second length of cable; one of these two men also carries the crank. After arriving at their destination the handle is removed and the telephone, which had previously been connected with the line, taken out from the cylinder on the side marked E. The receiving station is now established, or, if the line has to be continued, the end A of the cable of a second reel joined to the end of the first cable (in the latter case the telephone must, of course, be previously disconnected).

The winding up of the cable is effected by means of the crank; one of the two men holds with his left hand the handle of the reel, and with his right turns the crank.

The junction of two cables is made in two different ways. Either two ordinary double-binding screws are connected up in such a way that the places of junction of the outgoing and return line, in order to keep them insulated from each other, are kept several centimetres apart, or a special connecting piece is made in the following way:—

Two double binding screws, joined together but insulated from one another by indiarubber rings, are placed inside a wooden protecting pipe, and fastened to it by means of a wooden pin.

In either case the men laying the cable are instructed not to place the junctions on the bare ground, but to put some wood, stone, etc., beneath them, so as to prevent an earth in case of wet weather.

The laying of a cable of 500 m. length does not take more than five to six minutes, which is equivalent to the ordinary speed of marching.

The somewhat primitive manner of joining the cables by means of binding screws had, besides cheapness, the further advantage that the unprepared ends of a cable that had been either purposely cut, or accidentally torn, or severed by bullets, could be joined together without any further trouble.

The advantages of the hollow space in the portable reel are :—

1. The cable, being wound upon a reel of large diameter, is exposed to less strain, and therefore lasts longer.

2. The convenient transport of the telephones.

3. The possibility of an uninterrupted communication between the sending station and the men laying the cable, even when they are beyond range of hearing and of sight. They can always hear inside the reel a call made with the trumpet at the sending station. In case of such a call, the men have only to stop, take the telephone out of the case, and enter into communication with the sending station.

At the terminal station the cable is fixed to a strong gimlet, whose handle is provided with a binding screw, and the gimlet is stuck into a tree, paling, etc.

Since the first adoption, in 1881, of the telephone for the above purpose, rifle practice has been greatly extended, ranges have become longer, targets more varied, and it has been found necessary, in order to make the most economical use of a given cable, to introduce a more perfect system of joining the different lengths of cable. A sort of small splice-box has been specially constructed for this purpose, into which the previously prepared cable end has simply to be pushed and fastened by means of a special peg. For the details of this contrivance, we refer the reader to the "Electrotechnische Zeitschrift," No. III., 1883, p. 125.

CHAPTER XXX.

MISCELLANEOUS APPLICATIONS.

1.—*OPERATIC AND OTHER MUSICAL PERFORMANCES REPEATED BY THE TELEPHONE.*

237. IN the very earliest days of the telephone, music played at Philadelphia was transmitted, by means of Elisha Gray's musical telephone, to New York. Similar applications have since frequently been made, and amongst them may be mentioned some which attracted a good deal of attention at the time. We refer to the repetition of theatrical performances during the Paris Exhibition of 1881. The performances at the Opéra, Opéra Comique, and Théatre Français could be distinctly heard in a room of the Exhibition building set apart for this purpose. Not only the voices of the actors and actresses, the songs and the orchestra, but all the incidents of the performance—the applause and laughter of the audience, and, in some cases, the voice of the prompter, too—were faithfully repeated, and listened to with intense pleasure by a never-tiring crowd of visitors.

The following was the arrangement for the telephonic repetition of the performance at the Opéra :—[1]

[1] Du Moncel, La Lumière Electrique, IV., p. 375.

The conducting wires led from the Exhibition through the sewers to the stage of the Opéra, where they were connected to a number of Ader transmitters, with multiple contacts, as shown in Figs. 32 and 33, p. 66.

There were 10 transmitters of this kind at the Opéra, which were placed on either side of the prompter's box, along the footlights.

The receivers placed in the telephone rooms of the Exhibition were Ader's telephones, described on p. 50, and the installation of the batteries for the working of these multiple systems had nothing peculiar about it. They were placed wherever there was room for them, generally below the stage; but as polarisation would take place to a serious extent if their circuit remained closed during a whole performance, they had to be changed every quarter of an hour, and a switch had to be so arranged as to effect these changes instantaneously. This switch consisted of a board provided with as many spring plates as there were transmitters, and which allowed the switching on or off the batteries working the microphones.

The greatest difficulty which had to be encountered was to render the transmitter more sensitive to the voices of the singers than to the predominating sounds of the orchestra. This difficulty was overcome by M. Ader by the following contrivance :—

Let us suppose two microphonic transmitters placed on the stage at T and T′ (Fig. 282), and these transmitters separately connected by two distinct wires to two telephonic receivers, R and R′, which are applied to both ears to hear the actor, whom we will suppose to be placed at A. It is easy to understand that, the distance of this actor from transmitter T being less than that from transmitter T′, his song will be more distinctly reproduced by transmitter T than by T′, and the stronger impression will be produced on the left ear. If, on the contrary, the singer changes his position to A′, the opposite result will be obtained, and the right ear will receive the stronger impression. The sensation pro-

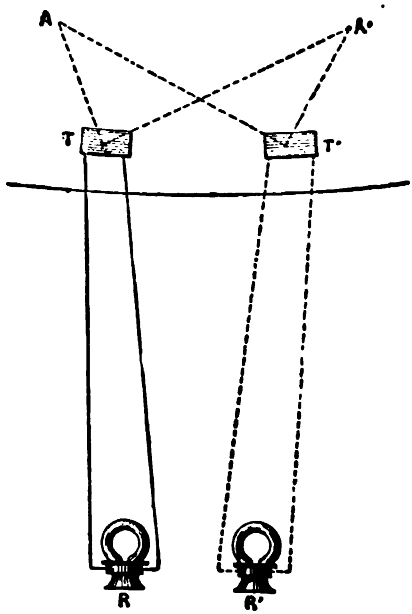


FIG. 282.

duced will, therefore, be a change of sonorous intensity from one ear to the other, consequent upon the displacement of the sound or of the singer from right to left, and the same will be the case for several actors crossing one another on the stage.

Now, we have mentioned that on each side of the prompter's box, along the footlights, five transmitters had been installed. Each of these transmitters had its separate circuit, and consequently its underground cable. On arrival at the audience room, each of the cables was connected to eight receivers, but always in such a way that for each listener the effects were quite distinct for each ear. Fig. 283 shows the arrangement of circuits for two transmitters, and it will be similar for all the others. It

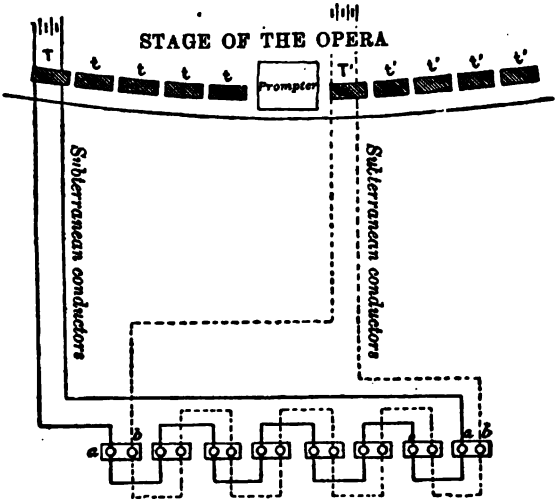


FIG. 283.

will be seen, on reference to Fig. 283, that on each board of the telephone room there was always one telephone, that on the left, which corresponded to the transmitters on the left of the stage, and a telephone on the right, which corresponded to the transmitters on the right. The telephones of each section were connected in series.

These telephonic repetitions have since been frequently repeated, not only at the Electrical Exhibitions of Munich and Vienna, but also in London, where the United Telephone Company have frequently conveyed Sullivan and Gilbert's operas to the Royal Society, and to several other places.

II.—*APPLICATIONS TO MEDICAL SCIENCE.*

238. An instrument of such marvellous sensitiveness as the telephone was bound to find, and has already found, several applications in medicine and physiology. The first apparatus of the kind was

(*a.*)—*Ducretet's Stethoscopic Microphone.*

With this instrument the observer can hear in several telephones at the same time the faintest pulsations,

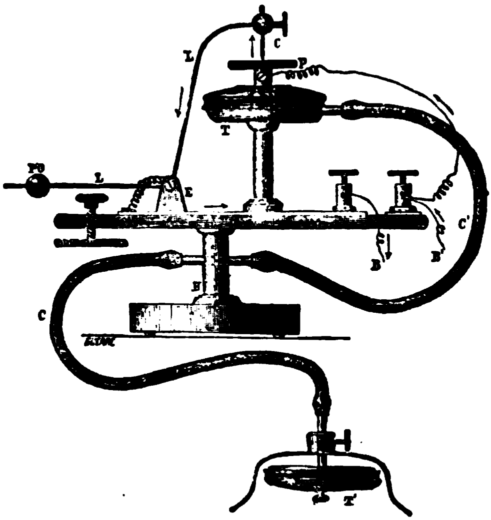


FIG. 284.

beating of the heart, of the pulse, and the arteries. Two of Marcy's drums, T′ and T (Fig. 284), are connected to the microphone. The one acts as sounder, and the other as receiver. The microphone is connected with a lever L, whose sensitiveness can be regulated by the counterweight P O. It terminates in a pencil, C, of gas carbon or graphite, which rests on a plate of the same substance, fixed on the receiving drum. The faintest motion communicated to the drum T′ acts, by the intermedium of the connecting indiarubber tube, on the drum T, and consequently on the microphone. The whole is joined in circuit with a battery of from one to three Daniell or Leclanché cells and the telephones for hearing the beatings of the sounding drum T′.

(*b.*)—*Boudet's Microphone applied to Medicine.*

239. A small and slightly concave plate of hardened india-rubber, 5 cm. by 2 cm., with a round hole

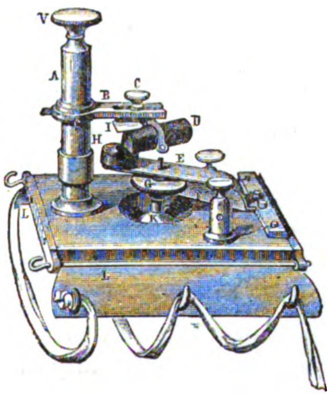


FIG. 285.

in its centre, forms the stand of the apparatus (Fig. 285). At one of its extremities stands a vertical rod, A, about

3 cm. high, upon which a very small copper waggon, I, is made to slide up and down by means of a regulating screw V. A carbon cylinder, D, 1½ cm. long and 5 mm. thick, oscillates on a transverse axis between the uprights of the waggon. A small horizontal spring E, one end of which is fixed to the opposite extremity of the caoutchouc plate, has fixed at its free end a carbon button H, which abuts against the carbon cylinder. Finally, underneath the first spring, and parallel to it, is another spring F, terminating in a sounding button K, which passes through the centre opening of the plate.

The least pressure exercised on the button K is transmitted by means of the springs F and E to the two carbon contacts, and causes a variation of strength in the passing current. These variations are received by a telephone, which the observer applies to his ear. The mobility of the carbons will account for the extreme sensitiveness of this microphone. It is, however, necessary in these experiments to obtain a certain amount of initial pressure. This can partly be obtained by means of the regulating screw, which can press the oscillating carbon cylinder more or less closely against the lower carbon. But this is not sufficient, for, on feeling a rather quick pulse, the motions communicated to the springs would suddenly raise the upper carbon, and cause a breaking of the circuit.

Boudet has obviated this inconvenience by placing in the waggon, above one extremity of the oscillating cylinder, a small piece of paper, bent in form of a **V**, which acts as a spring. The addition of this spring presents several advantages. Paper is a substance of inferior but very reliable elasticity. It lends itself, consequently, much more readily than steel and caoutchouc to the successive interruptions and approaches of the carbon contacts, or, rather, to the variations of their reciprocal pressure. The apparatus thus constructed, when applied to an artery, indicates all the murmurs that take place inside the vessel, and, with a little practice, the observer can easily distinguish differences of rhythm, the breath sounds, etc. The pulsation is very strongly accentuated, the normal dicrotism becomes perceptible; in one word, the tracings of the pulse are heard, such as they are registered by the sphygmograph. Applied to a muscle, the same instrument becomes an excellent myophone. It indicates the normal muscular sound, and when contraction takes place the characteristic rumbling noise of the phenomenon is distinctly heard.

Dr. Boudet has constructed a number of apparatus of the most ingenious kind, which were exhibited at Vienna in 1883, and which make use of the telephone for physiological research.

240. The *Myograph*, an instrument for measuring the nervous sensibility, consists of a probe, which is applied the lower part of the arm muscle, and an elastic to bandage, which is fitted to the upper part. The probe as well as the bandage are connected to an induction coil provided with a rheostat, and the probe is, besides, in connection with a registering apparatus. This latter consists of a cylinder covered with smoked paper, and is set in motion by a clockwork. The difference of nervous sensibility between the two parts of the arm are traced on the blackened paper in form of an irregular curve, or can be heard in a telephone placed in the circuit. If now a certain resistance is inserted

in the circuit, this irregularity disappears, and the more resistance is required to obtain a uniform tracing, or to obtain silence in the telephone, the greater is the nervous sensibility. A direct measurement of the latter is therefore obtained by registering the amount of resistance inserted in the circuit.

Another apparatus for measuring the acuteness of hearing is also most ingenious and interesting. It consists of an electric tuning fork and two cords in unison with it, which are connected with one another, as well as with a Bunsen element. In the same circuit is an induction coil with a rheostat, and also a microphone, with an ordinary Bell receiver. If the tuning fork and the two cords vibrate in unison, the telephone can be rendered silent by the insertion of a certain amount of resistance. But as soon as one of the cords is made to change its vibrations in the slightest degree a noise is heard in the telephone, and this noise is the louder the greater the variation in the vibrations of the cords. In order to render the telephone silent a fresh amount of resistance. must now be inserted, and, consequently, the more resistance the individual observer has to insert in the circuit, in order to hear a sound in the telephone, the more acute is his hearing. The amount of resistance inserted again affords a direct measurement of the acuteness of hearing.

III.—*HUGHES' INDUCTION BALANCE.*

241. This apparatus, which is represented in Fig. 286, consists of two tubes, T T′, each provided with a double induction coil A B, A′ B′, corresponding to two distinct circuits, in which are placed, on the one hand, an interrupter (through the coils B B′), and, on the other hand, a

telephone, which can be replaced by a sonometer by means of a commutator X. One of the systems has an adjustable lever L, which regulates the distance of coil A′ from coil B′, so as to obtain two equal induction effects.

If the circuits are so arranged that the currents induced in the coils A A′ are of contrary sense, it is clear that the interruptions of the primary current produced at *p* will give no sound in the telephone O;

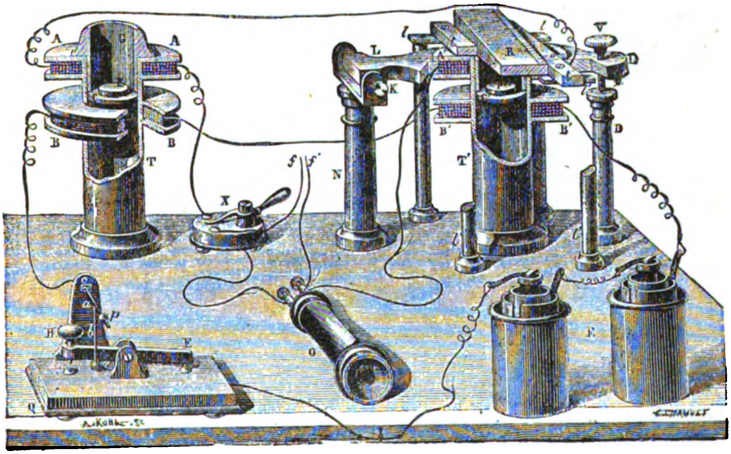


FIG. 286.

but if a piece of metal be placed at P, or any disturbance of equilibrium be introduced, the case will be altered, and the telephone will indicate the inductive disturbance caused by the disturbance of the existing balance.

Let us suppose now that, instead of placing the metallic piece at P, it be placed above A. A similar effect will be obtained, but much less energetic; and it will be easy to ascertain the distance at which this piece has been placed if, above the second system of coils A′ B′, a similar piece is placed, and is moved about until the sounds have died away in the telephone. If the two pieces are well in the axes of the two tubes T T′, their distance from the coils A A′ will be equal, and it will be sufficient to measure the one in order to know the other.

242. It will be easily understood how such an apparatus can, for instance, be arranged for finding a bullet which has gone astray in the interior of the human body. For this purpose the system A B,

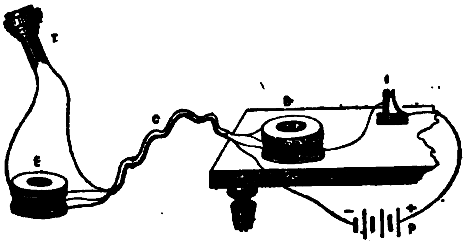


FIG. 287.

of Fig. 286, has only to be made movable, the tube to be cut at the level of the coils, and the connecting wires to be in the form of a flexible cord, so as to avoid any change of condition during the unavoidable displacement of the movable system. Care must, however, be taken that the coils of this system are in an inverted position to that of the fixed system A′ B′, since the action takes place in the reverse or upward direction if the body on which the operation has to be performed is placed horizontally. In Fig. 287 E is the couple of movable coils which the operator holds in his hand, and with which he performs his exploration ;

B is the fixed system placed on a table near the interrupter I of battery P; T is the telephone, which the operator applies to his ear during the whole time the operation lasts.

As long as the exploring coils are not near the bullet no sound is produced in the telephone, but as soon as they approach the bullet, warning is given by the sound increasing until the bullet is in the axis of the tube of the system.

The direction of the spot at which the bullet is lodged will be determined by a greater or lesser number of trials. For determining the depth, the method indicated above for the metallic pieces placed above the coils will be followed. A bullet of the same calibre as the one which is supposed to be lodged in the body of the patient is placed at the top of the tube of the fixed system, and is withdrawn from the upper coil or brought nearer to it, until sound is no longer produced in the telephone. The distance of the trial bullet indicates the depth at which the bullet is lodged in the body.

It will be remembered that this instrument was used by Professor Graham Bell in the treatment of the wound of the late President Garfield.

243. A most interesting application of the principle of the induction balance has been made by Professor Hughes in his recent researches *On the self-induction of an electric current in relation to the nature and form of its conductor.*[1]

The instrument is a combination of the "induction balance," with a "Wheatstone Bridge," and is called

[1] Journal of the Society of Telegraph Engineers, vol. xv., No. 60.

The Induction Bridge.

The resistance of the wire is measured and balanced by the bridge; the induced or extra currents are measured and reduced to zero by an equal opposed induced current from the induction balance.

The diagram, Fig. 288, shows the electrical connections. The bridge consists of a single German silver wire A K B ('25 mm. diameter, 1 metre in length, of 4 ohms resistance). This wire is supported upon two wooden arms articulated at K, by means of which the

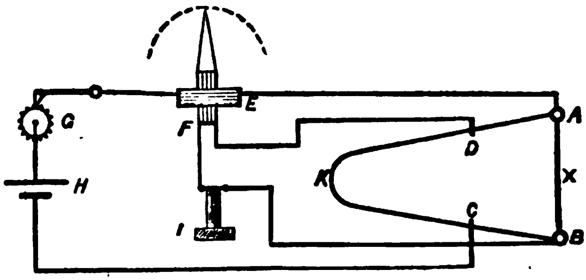


FIG. 288.

terminals A B can be more or less separated as desired. The wire (X) to be tested is joined to A and B, thus completing the closed circuit of the bridge.

The other connections are as shown: A is connected to the primary coil of the sonometer E, and through it to the spring of the interrupter or rheotome G, the interrupting wheel being connected to the battery H, and thence to the bridge at C. The wire from B passes through the telephone I to the secondary coil F, returning to D.

Great care has to be taken in the construction of the bridge, so that it shall be as free as possible from induced or extra currents; and for this reason resistance coils cannot be employed. The resistance of the wire X is balanced by sliding the connections D and C. It is evident that if all the arms of this bridge are equal in resistance, and in what Professor Hughes calls *inductive capacity*, there will be silence on the telephone; but if A B (X) be slightly stronger or weaker in inductive capacity, then we may be able to balance its resistance, but not its induction, as we shall then have a slight or a loud continuous sound due to the differential extra currents in the arm A B. These are compensated by the introduction in the circuit of the telephone of an equivalent but opposed induced current from the secondary coil of the sonometer F, the degree of angle through which this coil has turned to produce silence being a measure of the extra current. The induction sonometer consists of two coils only, one of which is smaller and turns freely in the centre of the outside coil. The exterior coil being stationary, the inner coil turns upon an axle by means of a long (20 cm.) arm, or pointer, the point of which moves over a graduated arc or circle. Whenever the axis of the interior coil is perpendicular to that of the exterior coil no induction takes place, and we have perfect zero; by turning the interior coil through any degree we have a current proportional to this angle, and in the direction in which it is turned. The value of the induction current for each sonometric degree was $\frac{1}{1000}$ the primary current which passed through the wire under observation, the latter being variable at will from ·001 to ·250 ampère. There is also a switch (not shown in the diagram) used to place the interrupter in the telephone circuit and close the battery circuit from H to A;

the conditions then giving the usual connections for ordinary testing, except using the telephone in place of a galvanometer. The telephone, being exceedingly sensitive and rapid, is most suitable, whilst a galvanometer would be too slow, and in fact useless for such researches.

IV.—*DIVING OPERATIONS AND DETECTION OF TORPEDOES.*

244. On the principle of Hughes' induction balance, Captain McEvoy has constructed an apparatus for detecting the existence of metal-cased torpedoes, sunken iron hulls, lost cables, anchors, or other metal objects, at the bottom of the sea.

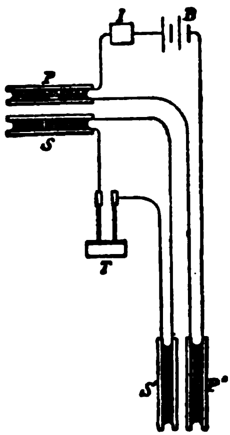


Fig. 289.

The principle of the apparatus will be understood from Fig. 289, where P S and P′ S′ are the four coils of the balance, arranged in pairs separated from each other and connected by insulated wires. The coils P and P′ are joined together through a battery B and a key or interrupter I, thus constituting the primary circuit of the balance. The coils S and S′ are connected through a telephone T, and constitute the secondary circuit of the balance. The interrupter I may be worked either by hand or automatically so as to give a continuous action. Whenever the primary circuit is closed, a current traverses the primary coils P, P′, and induces a corresponding current in the secondary coils S, S′. This current would, of course, be audible in the telephone T, were it not that one of the secondary coils, say S′, is reversed, by which a practically perfect balance between the two induced currents is effected, and silence obtained in the telephone.

This is done by making the two primary coils and also the two secondary coils alike in all respects, and placing the secondary S at the same distance from P that S′ is from P′. The final adjustment to produce silence in the telephone can be made by altering the distances between a secondary coil and its primary, say the distance of S from P, or it can be made by means of a small piece of metal adjusted near one pair of coils, as was originally shown by Professor Hughes. To employ this arrangement for detecting metal masses, it is only necessary to obtain a sufficiently good balance in this way, and to explore the field where the metal is supposed to lie by moving about the pair of coils S′, P′. Then, if these coils come near a piece of metal, the inductive disturbance which its presence creates will upset the existing balance, and the telephone, before silent or nearly so, will give out distinctly audible sounds, owing to the predominance of the induced currents in the secondary S′ over those in the secondary S.

The actual apparatus employed is shown in Fig. 290, where A is a portable case containing the adjustable coils P S and the interrupter I of Fig. 289; B is a voltaic battery of two cells, which may be replaced by a small magneto-electric machine giving alternate currents; T is the telephone in the secondary circuit; C is the insulated cable containing the wires connecting up the two pairs of coils; and D is the detecting or exploring case, containing the two secondary coils S′ P′ of Fig. 289. The coils P S inside the box A are separated by a layer of soft indiarubber, and an ivory screw passes through both coils and the rubber washer between. An ebonite head to the screw is adjusted by hand so as to press the

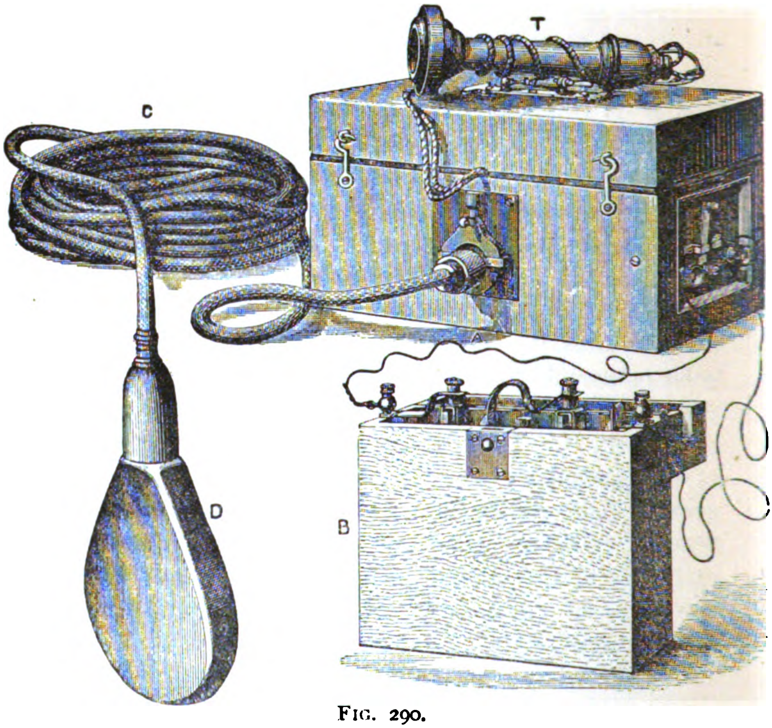


FIG. 290.

coils together or let them further apart by regulating the pressure between them and the indiarubber. This simple device adjusts the balance of induction and reduces the telephone to silence, or (as the inventor prefers it) to all but silence. When the ear has a slight sound to guide it, the notable increase of loudness in that sound, produced by the approach of the detecting case D to a metal body, is perhaps more readily observed.

The interrupter consists of a small iron reed or tongue kept in vibration by a small double-poled electro-magnet, and thereby interrupting the current a certain number of times per second, so as to give out a definite note, which is easily recognizable in the telephone, and cannot be mistaken. A switch E at the end of the box turns the current from the battery on and off at a moment's notice.

The battery consists of two Leclanché cells in a portable case; a substitute for the battery and interrupter is also provided in the shape of a small magneto-electric machine such as are used in the medical applications of electricity.

The telephone is the ordinary Bell receiver, and it, as well as the magneto machine, is packed inside the box.

The cable C is insulated with indiarubber having its pores filled up with ozokerit, or black earth wax, forced in under pressure when in a hot fluid state. It is further protected with an outer braided sheathing, and is fitted to the box A by a socket, by means of which connection is made between the corresponding primaries and secondaries. The detector case D is made of wood soaked in paraffin wax, and its peculiar powder-flask shape as well as its material were only arrived at after many trials. It is water-tight, and contains the two exploring coils. When it is lowered into the water by cable C, and moved about or dragged over the bottom, the instant it comes against a piece of metal, such as a torpedo-case, a chain, or a submarine cable, the balance is disturbed, and the noise heard in the telephone very faintly until now, becomes unmistakably loud and clear.

V.—*LOCALISING FAULTS IN CABLES.*

245. The methods employed for localising faults in an underground or submarine cable require a practised and competent electrician, and in many cases do not allow of an accurate determination of the locality of the fault. It is difficult, for instance, to determine an earth contact in an underground telegraph cable with an approximation exceeding one hundredth of the length of the cable; so that, if the line is one kilometre long, it becomes necessary to dig trenches over a distance of about ten metres to get at the faulty part. The measurements are even more difficult, and the results still less accurate, when the conductors have a large cross-section, as is the case with electric light cables. In the latter case a fault can only be localised by arranging a large number of openings all along the line, so as to be able to test the cable in sections.

Mr. Eric Gérard proposes to use telephonic induction for the purpose of localising faults. It has been repeatedly stated that these inductive effects are produced when the telephone circuit is close to another circuit traversed by intermittent currents, and that these effects are the chief obstacle to telephonic communication over a long distance.

The ingenious idea of utilizing these injurious effects is practically carried out by Mr. Eric Gérard in the following way:—

One of the extremities of the cable is insulated, and an intermittent current sent from the other extremity by a battery, one of whose poles is to earth. The operator then follows the cable, starting from the interrupter, while holding in one hand a coil whose soft iron core preserves a direction parallel to that of the cable, and with the other hand holding to the ear a telephone connected to the ends of the coil. The intermittent currents traversing the cable between the battery and the faulty section produce in the coil induced currents, which are distinctly heard in the telephone. At the moment when the faulty section is reached the noise suddenly stops, or is greatly reduced, and the fault can thus be determined with surprising rapidity and distinctness.

The interrupter used is a clockwork mechanism whose metallic mass communicates with the cable; an elastic strip connected to the battery works over the teeth of one of the wheels, and causes the necessary interruptions. The resistance of the telephones used for the experiments varied between 100 and 200 ohms. The soft-iron core of the coil is formed of a bundle of annealed and insulated iron wires. The coil ought to have as many windings as possible, and its resistance must be in proportion to that of the telephone employed. The mean primary current was observed in a periodic galvanometer.

VI.—*BRITISH POST OFFICE WIRE-FINDER.*

246. In the British Post Office Telegraph system instruments based on the same principle as the foregoing have been devised for picking out any

required wire upon an underground line. The most approved plan is arranged in the following way :—

At the terminal office an electro-magnet with an automatic make and break (called a "buzzer") is joined up with a battery, and the two ends of the coil are also connected respectively to earth and to the line to be traced. The "extra currents" from the electro-magnet thus pass to the line.

The "wire-finder" itself consists of a coil in two sections hinged together on one side, so that it can be readily clamped around a line wire, and the ends of this coil are joined to a telephone receiver. The coil is really an iron cylinder wound longitudinally, so that the convolutions are in line with the axis, and, consequently, when a wire is inserted between the sections, currents passing in the wire induce secondary currents in the coil, which produce sounds in the telephone receiver attached. The wire in which the characteristic intermittent currents from the buzzer are passing can thus be easily picked out at any one of the flush boxes upon the underground line.

APPENDIX.

THE TELEPHONE IN LONDON.

THE United Telephone Company is the parent of all the Companies in England, and it has rigidly and successfully maintained its patent rights against every attack. Its repressive policy has, however, been severely condemned by some, and the backwardness of telephony in England is attributed by others not only to the monopoly so rigidly maintained, but to the apparent inefficiency of the service in London, and to the supposed restrictions of the Government, which has the temerity to demand a tax for the great privilege it grants the Telephone Companies of carrying on a lucrative business with rights that belong exclusively to the Post Office. Telephony, however, flourishes in America, where taxes and restrictions are far greater, where the service is often carried out no better, and where the monopoly is as strict. But telephony is more of a necessity in America than it is in England, and it suits the climate and the people. The service might perhaps be better performed, but the size of London and the climate of England greatly militate against good work. The vastness of London and the difficulty of obtaining wayleaves make it next to impossible to organise a complete and thorough working system. It is a congregation of cities, and must necessarily possess a number of Exchanges, which have to be connected together by means of trunk wires. The only other city that compares with it is New York, but there, through the peculiar geographical structure of the country around, the conditions are simple compared with London. Nevertheless, copper wire, metallic circuits, underground wires, multiple switchboards, with centralization of Exchanges and modern apparatus would go a long way toward making telephone working in London all that could be desired.

There are now (November, 1888), in London 4,900 subscribers with 5,150 instruments in connection with Exchanges, and 1,400 private renters. There are twenty-one Exchanges, connected by 550 trunk wires. A system of concentration is now going on by which the number of Exchanges in use will be reduced to a minimum. At several of the Exchanges multiple boards are being used. There are seven fixed, and four are now in hand. The magneto call system is being gradually introduced in preference to the battery which previously existed, and at some Exchanges the subscribers are called by means of small magneto machines driven by hot-air motors. The service is a day and night one.

BRITISH WIRE GAUGE.

Showing Areas of Cross Section of Round Wire, and Resistance, Conductivity, and Weight for IRON Wire.

No. of British Wire Gauge.	Diameter.		Area of Cross Section, square cms.	Iron.			No. of British Wire Gauge.
	Ins.	Cms.		Resistance, ohms per metre.	Conductivity, metres per ohm.	Weight, grammes per metre. Density 7·79.	
7/0	·500	1·270	1·267	·00080	1245·3	986·8	7/0
6/0	·464	1·178	1·090	·00093	1071·8	849·0	6/0
5/0	·432	1·097	·945	·00106	943·4	735·9	5/0
4/0	·400	1·016	·811	·00125	800·0	631·3	4/0
3/0	·372	·945	·701	·00145	689·7	546·3	3/0
2/0	·348	·884	·613	·00166	602·4	477·8	2/0
0	·324	·823	·532	·00191	523·6	414·2	0
1	·300	·762	·456	·00223	448·4	355·5	1
2	·276	·701	·386	·00264	378·8	300·5	2
3	·252	·640	·322	·00316	316·5	250·8	3
4	·232	·589	·273	·00373	268·1	212·8	4
5	·212	·538	·228	·00446	224·2	177·4	5
6	·192	·488	·187	·00544	183·8	145·6	6
7	·176	·447	·157	·00648	154·3	122·4	7
8	·160	·406	·130	·00784	127·6	100·9	8
9	·144	·366	·105	·00968	103·3	82·0	9
10	·128	·325	·0829	·0122	81·97	64·6	10
11	·116	·295	·0682	·0149	67·11	53·1	11
12	·104	·264	·0548	·0185	54·05	42·7	12
13	·092	·234	·0429	·0236	42·37	33·4	13
14	·080	·203	·0324	·0314	31·85	25·3	14
15	·072	·183	·0263	·0387	25·84	20·5	15
16	·064	·163	·0208	·0489	20·45	16·2	16
17	·056	·142	·0159	·0642	15·58	12·3	17
18	·048	·122	·0117	·0873	11·45	9·10	18
19	·040	·1016	·00811	·125	8·000	6·29	19
20	·036	·0914	·00657	·154	6·493	5·11	20
21	·032	·0813	·00519	·196	5·102	4·04	21
22	·028	·0711	·00397	·256	3·906	3·10	22
23	·024	·0610	·00292	·349	2·865	2·28	23
24	·022	·0559	·00245	·415	2·410	1·91	24
25	·020	·0508	·00203	·502	1·992	1·58	25
26	·018	·0457	·00164	·618	1·618	1·28	26
27	·0164	·0417	·00136	·742	1·348	1·06	27
28	·0148	·0376	·00111	·915	1·093	·865	28
29	·0136	·0345	·000937	1·087	·9200	·730	29
30	·0124	·0315	·000779	1·307	·7651	·607	30

Gauges 31–50 omitted from above Table.

BRITISH WIRE GAUGE:

Showing Areas of Cross Section of Round Wire; and Resistance, Conductivity, and Weight for COPPER Wire.

No. of British Wire Gauge.	Diameter.		Area of Cross Section, square cms.	Copper (Pure).			No. of British Wire Gauge.
	Ins.	Cms.		Resistance, ohms per metre.	Conductivity, metres per ohm.	Weight, grammes per metre. Density 8·90.	
7/0	.500	1·270	1·267	·000135	7402·	1127·4	7/0
6/0	.464	1·178	1·090	·000157	6370·	970·2	6/0
5/0	·432	1·097	·945	·000181	5521·	840·8	5/0
4/0	·400	1·016	·811	·000211	4736·	721·3	4/0
3/0	·372	·945	·701	·000244	4098·	624·2	3/0
2/0	·348	·884	·613	·000279	3584·	545·9	2/c
0	·324	·823	·532	·000322	3107·	473·2	0
1	·300	·762	·456	:occ375	2666·	406·1	1
2	·276	·701	·386	·000444	2253·	343·2	2
3	·252	·640	·322	·000532	1881·	286·5	3
4	·232	·589	·273	·000628	1592·	242·5	4
5	·212	·538	·228	·000751	1331·	202·7	5
6	·192	·488	·187	·000916	1092·	166·3	6
7	·176	·447	·157	·00109	917·8	139·8	7
8	·160	·406	·130	·00132	757·2	115·3	8
9	·144	·366	·105	·00163	614·9	93·7	9
10	·128	·325	·0829	·00206	484·6	73·8	10
11	·116	·295	·0682	·00251	398·3	60·7	11
12	·104	·264	·0548	·00312	320·3	48·8	12
13	·092	·234	·0429	·00398	250·6	38·2	13
14	·080	·203	·0324	·00528	189·5	28·9	14
15	·072	·183	·0263	·00651	153·5	23·4	15
16	·064	·163	·0208	·00824	121·3	18·5	16
17	·056	·142	·0159	·0108	92·7	14·1	17
18	·048	·122	·0117	·0147	68·2	10·4	18
19	·040	·1016	·00811	·0211	47·4	7·19	19
20	·036	·0914	·00657	.0260	38·4	5·84	20
21	·032	·0813	·00519	·0330	30·3	4·62	21
22	·028	·0711	·00397	·0431	23·2	3·54	22
23	·024	·0610	·00292	·0587	17·05	2·60	23
24	·022	·0559	·00245	·0698	14·32	2·18	24
25	·020	·0508	·00203	·0845	11·84	1·80	25
26	·018	·0457	·00164	·104	9·59	1·46	26
27	·0164	·0417	·00136	·125	7·97	1·21	27
28	·0148	·0376	·00111	·154	6·48	0·988	28
29	·0136	·0345	·000937	·183	5·46	·834	29
30	·0124	·0315	·000779	·220	4·55	·693	30
31	·0116	·0295	·000682	·251	3·98	·607	31

BRITISH WIRE GAUGE (*Contd.*).

No. of British Wire Gauge.	Diameter.		Area of Cross Section, square cms.	Copper (Pure).			No. of British Wire Gauge.
	Ins.	Cms.		Resistance, ohms per metre.	Conductivity, metres per ohm.	Weight, grammes per metre, Density 8·90.	
32	·0108	·0274	·000591	·290	3·45	·526	32
33	·0100	·0254	·000507	·338	2·96	·451	33
34	·0092	·0234	·000429	·398	2·51	·382	34
35	·0084	·0213	·000358	·478	2·09	·318	35
36	·0076	·0193	·000293	·585	1·71	·260	36
37	·0068	·0173	·000234	·730	1·37	·208	37
38	·0060	·0152	·000182	·943	1·06	·162	38
39	·0052	·0132	·000137	1·248	·801	·122	39
40	·0048	·0122	·000117	1·466	·682	·1038	40
41	·0044	·0112	·0000982	1·742	·574	·0874	41
42	·0040	·0102	·0000811	2·109	·474	·0722	42
43	·0036	·00914	·0000656	2·611	·383	·0584	43
44	·0032	·00813	·0000519	3·300	·303	·0462	44
45	·0028	·00711	·0000397	4·310	·232	·0353	45
46	·0024	·00610	·0000292	5·848	·171	·0260	46
47	·0020	·00508	·0000203	8·475	·118	·0180	47
48	·0016	·00406	·0000129	13·23	·076	·0115	48
49	·0012	·00305	·0000073	23·42	·043	·00650	49
50	·0010	·00254	·0000050	33·78	·030	·00451	50

Area in square cms.	×	·155	= area in square ins.
Ohms per metre	×	·305	= ohms per foot.
Metres per ohm	×	3·28	= feet per ohm.
Grammes per metre	×	·000672	= lbs. per foot.
,, ,,	×	·01075	= ozs. ,, ,,
,, ,,	×	4·7	= grs. ,, ,,
Length in millimetres	×	·03937	= length in inches.
,, ,, centimetres	×	·3937	= ,, ,, ,,
,, ,, metres	×	3·2809	= ,, ,, feet.
,, ,, ,,	×	1·0936	= ,, ,, yards.
,, ,, kilometres	×	·62138	= ,, ,, miles.
Weight in grammes	×	15·432	= weight in grains Troy.
,, ,, kilogrammes	×	2·2	= ,, ,, lbs. Avoirdupois.

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