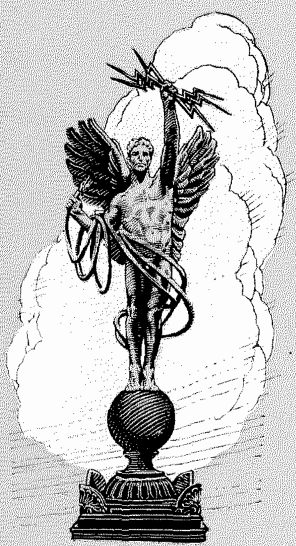
ELECTRICAL COMMUNICATION



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RESEARCH LABORATORIES
of the
AMERICAN TELEPHONE AND TELEGRAPH COMPANY
and
WESTERN ELECTRIC COMPANY

The Bell System Research Laboratories

By EDWARD B. CRAFT

Chief Engineer, Western Electric Company, Inc., and International Western Electric Company

THE genius of one man gave us the speaking telephone. The labors of an army of scientists, engineers and workers of all sorts extending over a period of fifty years has given us the present-day system of telephonic communication.

There were many fortuitous circumstances incident to the birth of the telephone.

First, it was associated with the electrical art, the scientific aspects of which were then and have ever since been the subject of the most enlightened kind of research and development.

Second, its development and commercial exploitation came into the hands of men with imagination and foresight—men with a keen appreciation of the value and necessity of the scientific development of the technique of the art.

Lastly, its place of birth was a new country of vast dimensions as to population and area, where a rapid and convenient means of communication was of greatest necessity and value.

The history of the development of the telephone in America has been a succession of scientific achievements followed by immediate and large scale application, so that today the Bell Telephone System represents one of the largest aggregations of capital and personnel to be found in the industrial world. Its engineering and scientific achievements combined with those of others in many parts of the world, have resulted in a system of telephone communication by means of which whole continents can be served by a universal, effective and economical means of inter-communication.

It is the purpose of this brief contribution to tell our readers something of the Bell System Research Laboratories which from the beginning have occupied an important place in the group of organizations comprising the Bell Telephone System.

For a considerable period, laboratories were operated by the American Telephone and Telegraph Company in Boston and by the Western Electric Company in New York City and in Chicago. In 1907–8, in the interest of greater efficiency, it was decided that they should be combined in New York City at the Western Electric Company's Bethune and West Street building. The fact that there were no divergent interests made this possible; certain kinds of apparatus being developed at the expense of one company and other kinds at the expense of the other, by agreement, and all patents resulting from this work being either owned or controlled by the American Telephone and Telegraph Company.

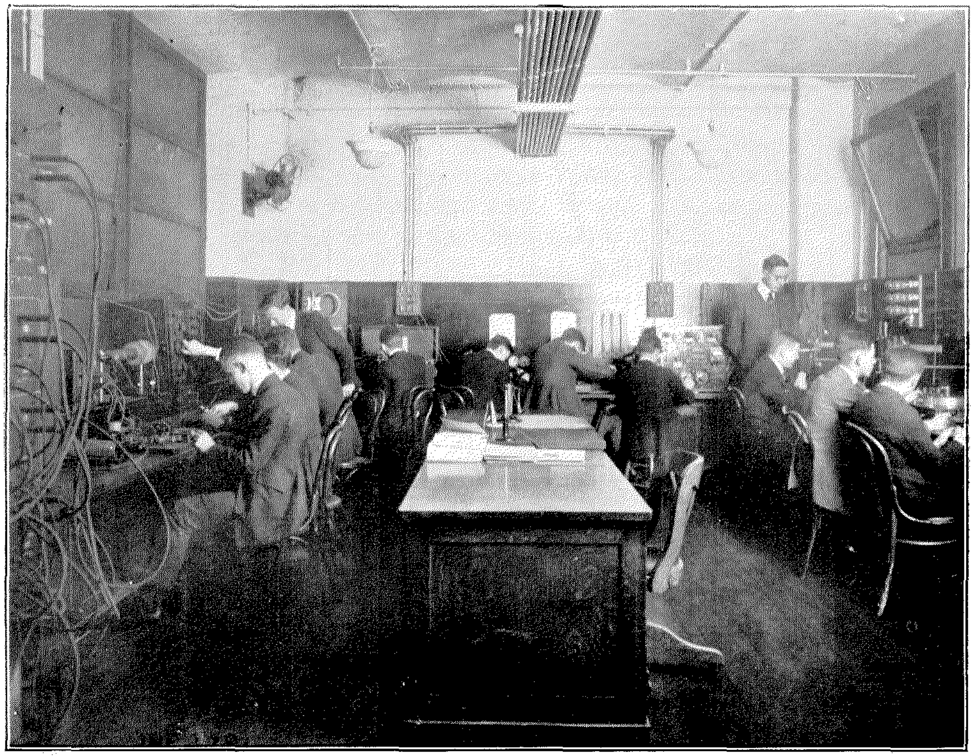
The operation of the laboratories is entrusted to the Engineering Department of the Western Electric Company, Incorporated, and they are located in New York City in a thirteen story building comprising a floor area of more than 400,000 square feet.

The personnel is made up of more than three thousand workers, whose sole function is the carrying on of research and development looking toward more effective and more economical means of electrical communication. Physicists, chemists, metallurgists, engineers, mechanics and many other classes of workers are combining their efforts in a systematic and coordinated attack on the manifold and never-ending succession of problems, the solution of which has resulted in the telephone system of today and will without doubt very largely determine the telephone systems of the future.

Operating problems of the Bell Telephone System as gathered from the field or originated in the Department are studied by the Department of Development and Research of the American Telephone and Telegraph Company and formulated as problems to be solved either by or for that Department, or by the Engineering Department of the Western Electric Company, Incorporated.

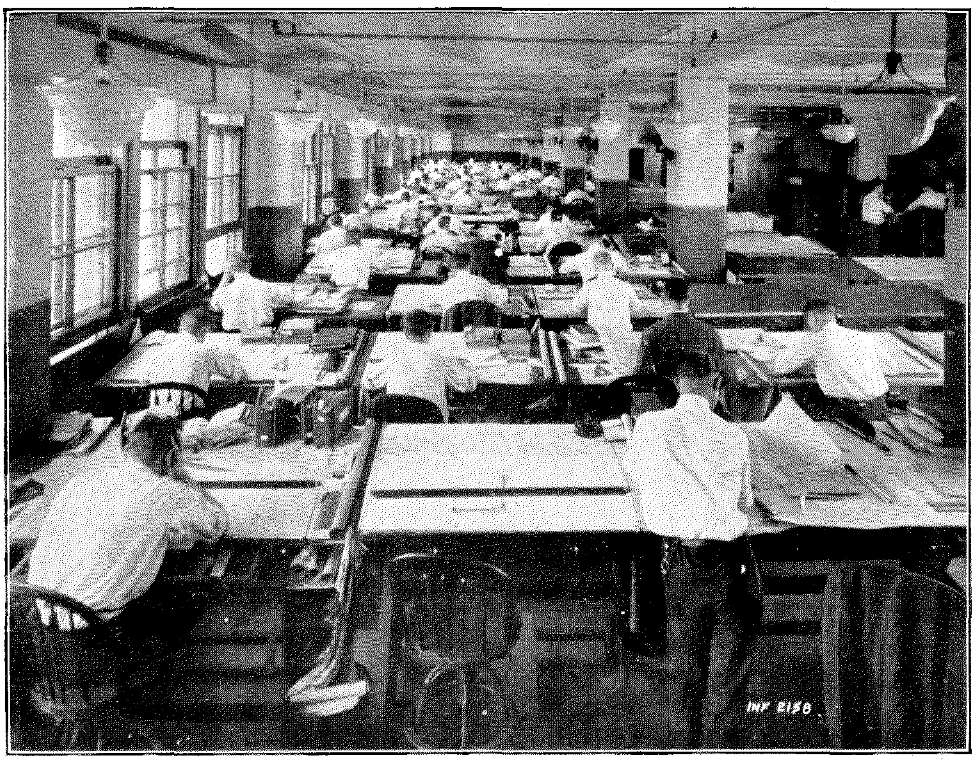
Because of the very considerable number of workers, and the variety and number of problems, a certain amount of formal organization is essential. The various units of the organization are built up on a functional basis, each

Historical Museum

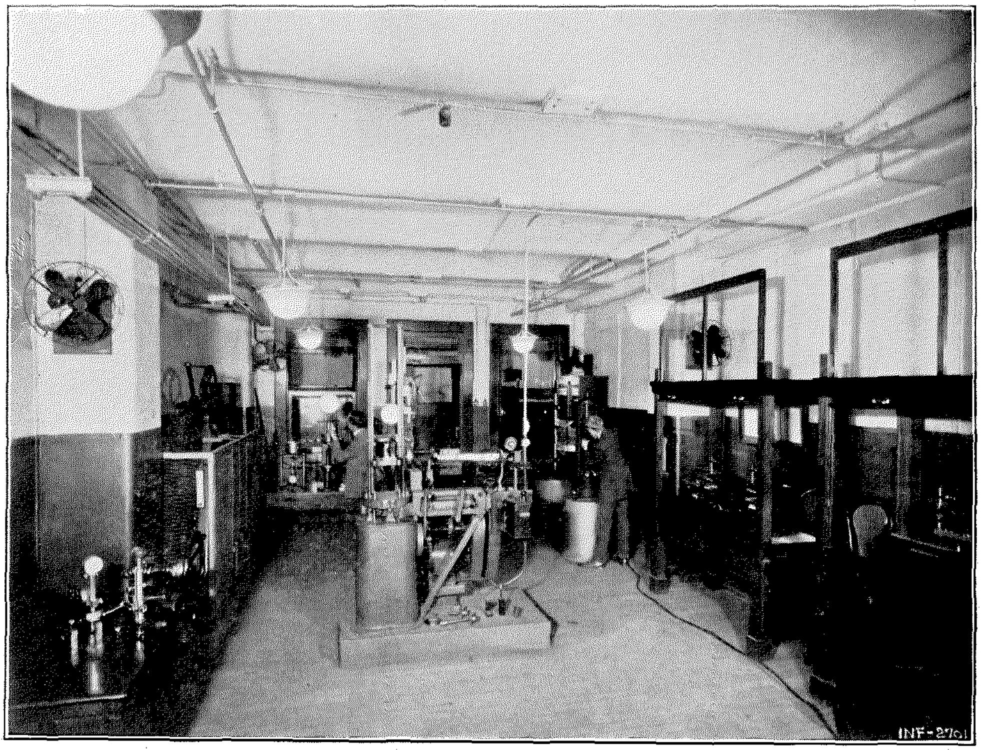


Educational Department Instruction Laboratory

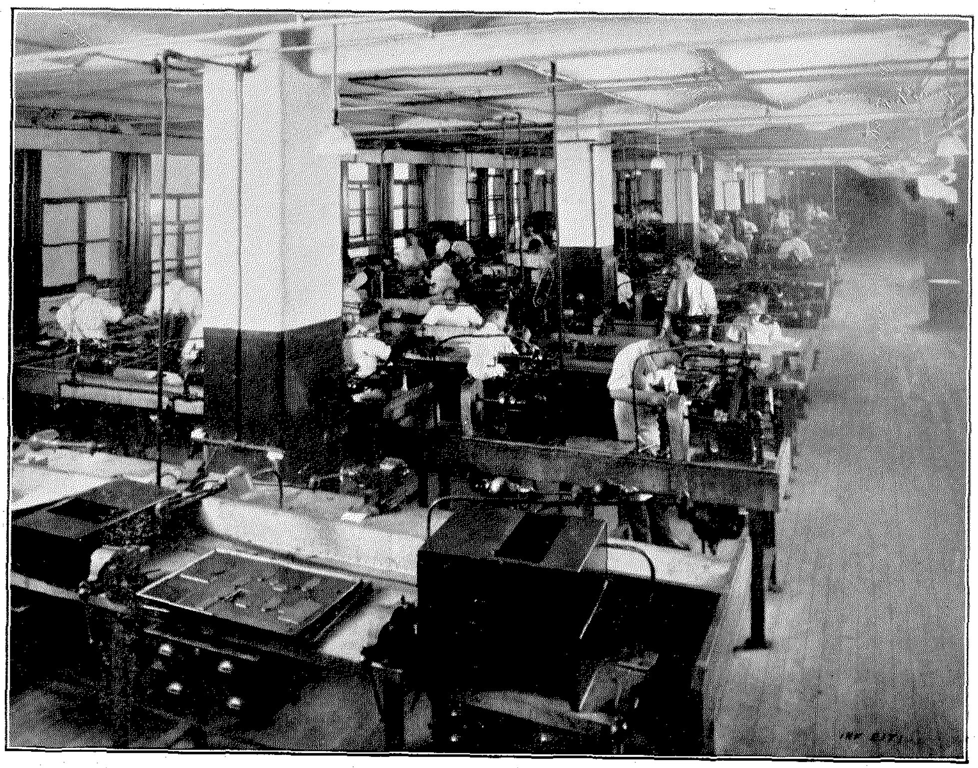
Library Reading Room



One of the Drafting Rooms



Materials Testing Laboratory



Experimental Machine Shop

unit whether it be made up of physicists, chemists, systems engineers or any other of the classes employed, is organized to carry on the work in its particular field and is equipped with the laboratory facilities peculiar to its own class of work.

The problem to be solved may require the consideration of one or more of these groups and whatever the number, each contributes that which he is best qualified to do. As a result, each problem receives the benefit of the attention of experts in any field the direction of its development may take.

While in no way limiting the scope or initiative of the individual worker, this plan provides for the application of a very large amount of cooperative talent to any specific problem.

In addition to the laboratory facilities involving as they do an investment of several millions of dollars, there are provided all the necessary auxiliary services for a completely self-contained operating unit.

Machine shops for the construction of operating models for laboratory and field trial, drafting rooms for the preparation of experimental and manufacturing drawings, a library with a corps of translators and abstractors for the accumulation and distribution of technical data, educational and training classes for the younger personnel, all contribute to the effective carrying on of the primary function of research and development.

To review the accomplishments of this organization would be to relate the story of the development of the communication art, but a brief statement of some of the outstanding achievements of the past ten years will serve to illustrate the character of their work and its effect upon the industry.

Any telephone system can be considered a system of transportation in which the commodity transported is intelligence in the form of articulate speech. A large portion of the research effort has always been directed to the problem of converting speech into an electrical condition, its transmission to a distant point and its reconversion into mechanical energy in the form of speech. To assist in the determination of the best instrumentalities to be employed, consistent effort has been made to get away from the old empirical methods and build up a system based on a scientific consideration of the fundamentals of speech and audition.

The elements of speech most essential to proper intelligibility, the factors of extraneous noises whether they be mechanical or electrical, have been subject to quantitative study. These studies have resulted in a much more intelligent understanding of the elements that must be taken into account in the design of lines and instruments.

The electrical transmission features of the problem are peculiar to themselves, and an entirely new art as to the measurement and control of these extremely delicate and complex phenomena has been built up, so that the trial and error methods of earlier days have been supplanted by the methods of the physicist and mathematician.

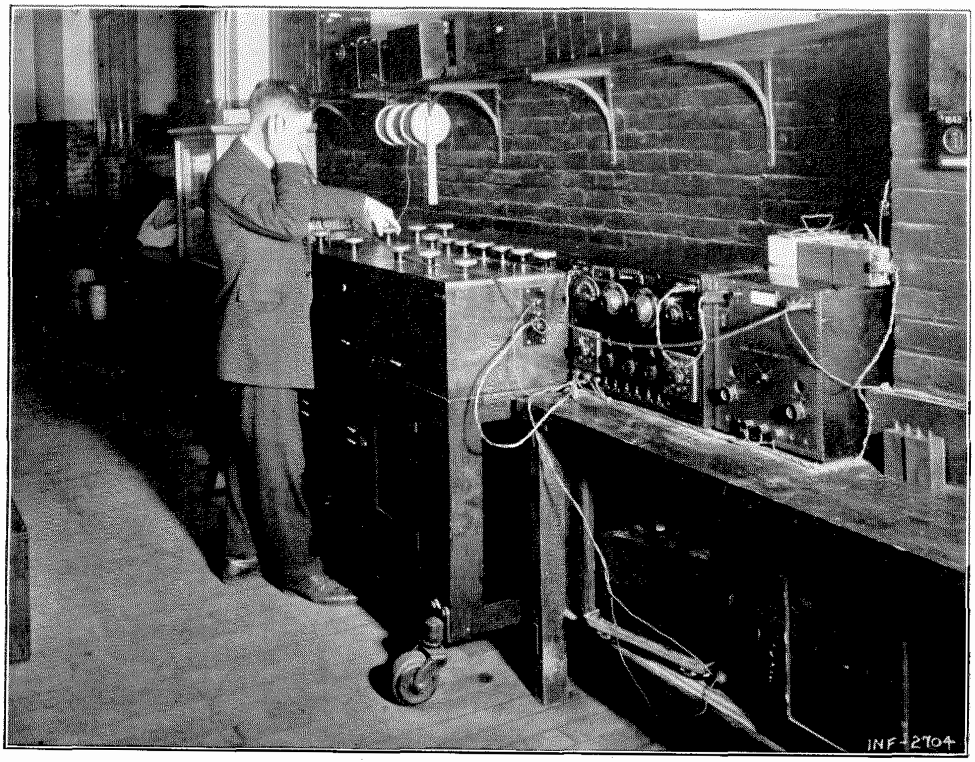
Probably no single advance has contributed so largely to change our whole picture of the art as the advent of the thermionic valve or vacuum tube as it is designated in America. Located in a practically unexplored field of physical phenomena, the laws governing its operation and structures best adapted to meet some useful purpose, have received constant and intensive study by the laboratory organization. This work has resulted in the transformation of a crude and unwieldy device into an instrument of precision of tremendous commercial value.

The fields which have been opened up by the commercial production of vacuum tubes of great uniformity and long life are much greater than might be ordinarily considered.

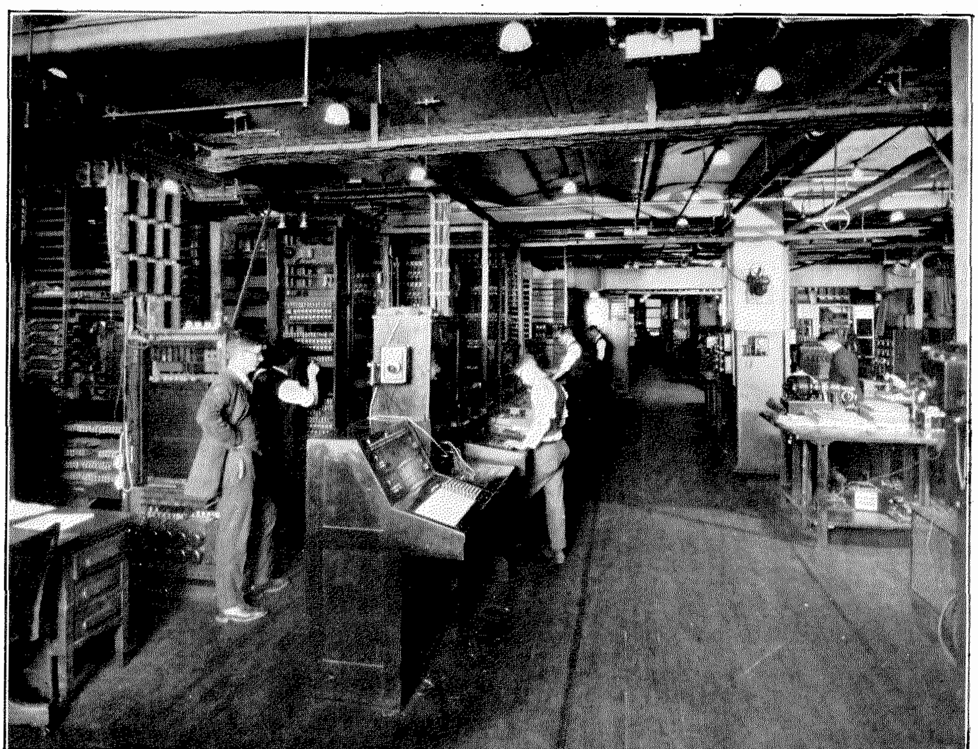
One of the most valuable applications has been in the extension of the range of long distance telephony. The vacuum tube telephone repeater has made possible telephonic transmission over practically unlimited distances. Conversations over distances of four to five thousand miles involving the use of twenty or more repeaters are no longer uncommon.

The repeater has also brought great advances in the use of telephone cables for long distance transmission, with the attendant gain in the reliability of service. Cable systems a thousand miles in length are in the process of installation.

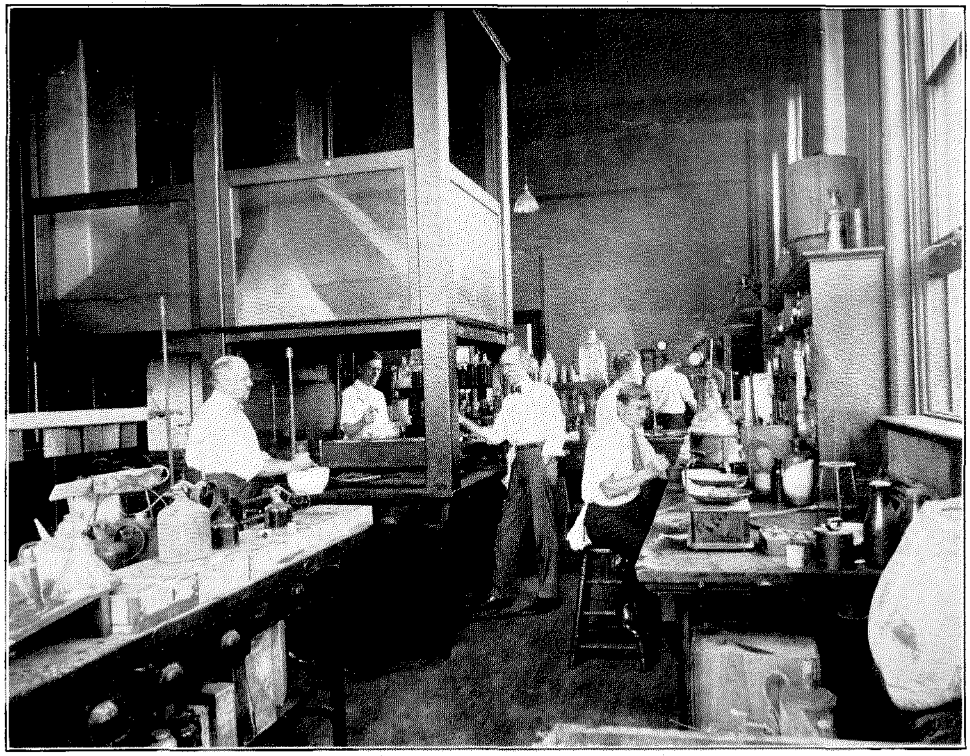
The subject of radio transmission, par-



One of the Carrier Current Testing Laboratories



One of the Machine Switching Laboratories



One of the Chemical Laboratories

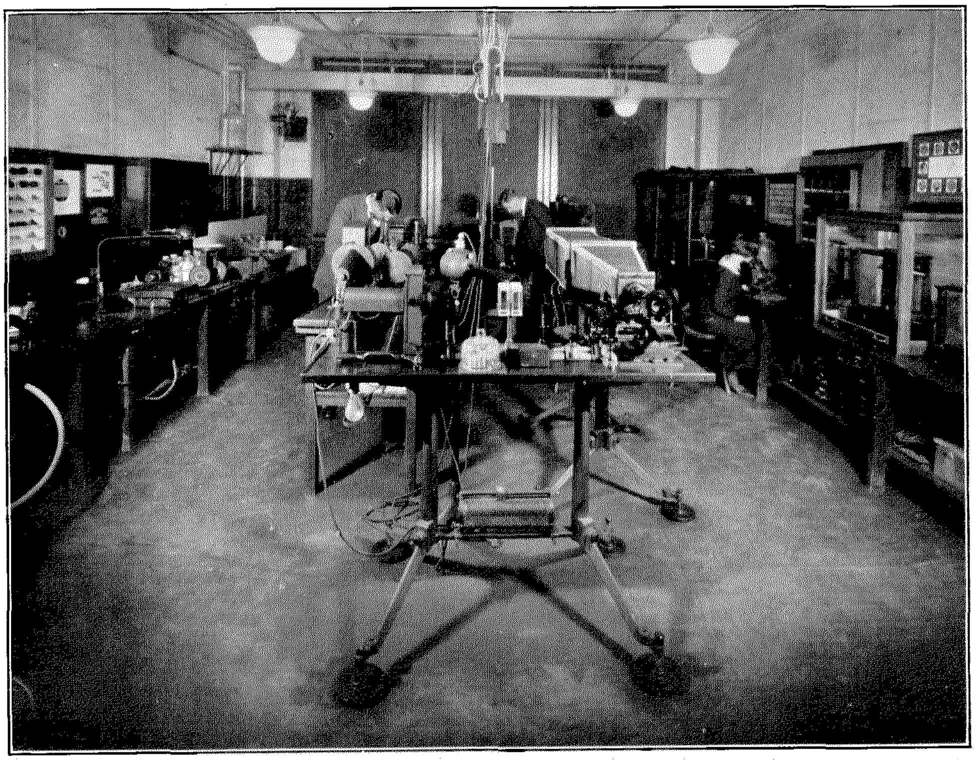
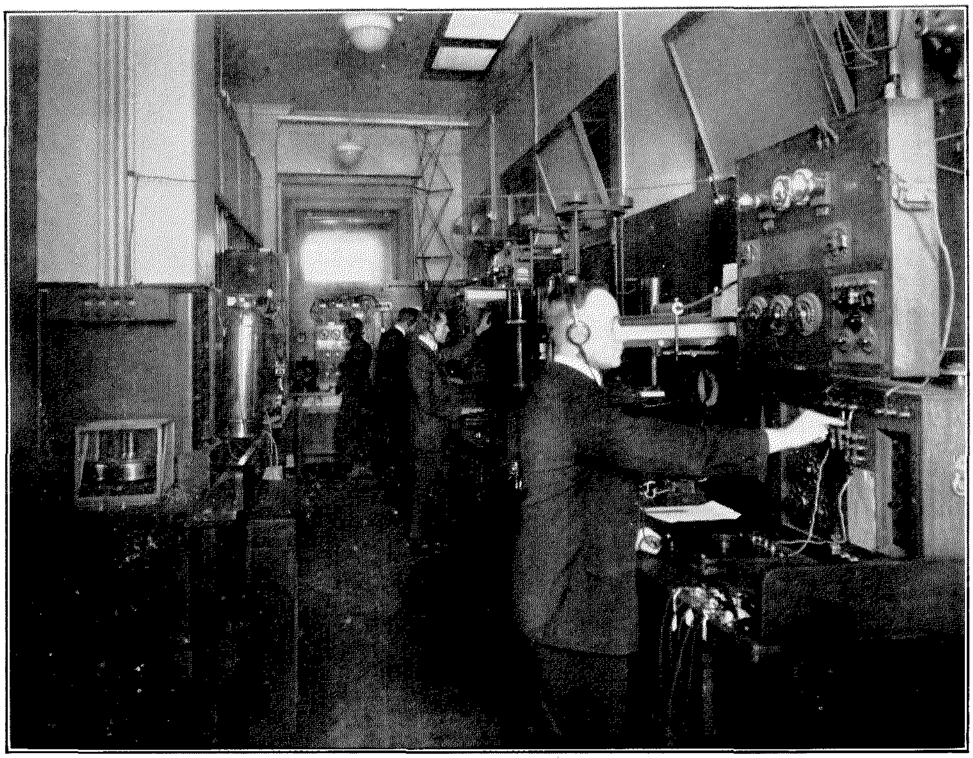


Photo-Micrographic Laboratory



One of the Transmission Research Laboratories

One of the Systems Development Laboratories ticularly radio telephony, has been one of the important problems of research and commercial development.

The first important tests of radio telephony were made in the year 1915, when speech was distinctly heard from New York by way of the Arlington radio station near Washington, in Paris, Panama and Honolulu. Since that time developments have been rapid along a variety of lines. As a result of the successful development of the high power vacuum tube of an output of from 10 to 20 kilowatts, more complete and satisfactory demonstrations of trans-Atlantic telephone transmission have been made during the past year, when scheduled telephonic communication was established with England.

Radio broadcasting, which carries music and speech to hundreds of thousands of homes, has been brought to a high state of perfection and a large proportion of the most successful broadcasting stations are equipped with apparatus developed in the Bell System Laboratories.

Another development in the transmission field in which the vacuum tube has played an important part, is that relating to the more effective utilization of the wire plant through the use of carrier currents.

A variety of systems have been developed which permit the operation of a considerable number of telephone and telegraph circuits over a single pair of wires. In the case of telephony as many as five simultaneous conversations are possible over a single circuit. The same system applied to telegraphy affords twenty operating channels over a single pair of wires. The economies which can thus be obtained over lines of considerable length are large, and the service rendered has proved highly successful in a large number of installations which are in constant commercial operation.

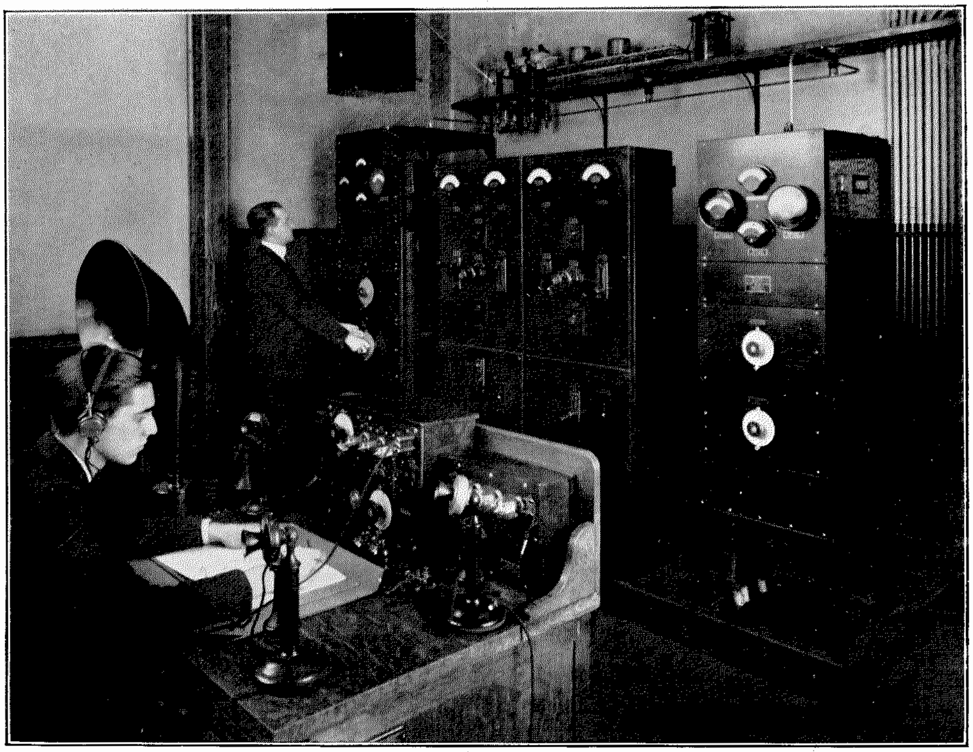
Multiplex printing telegraphy has found an important place in the communication system, and by its use as many as eight telegraph messages may be sent in each direction over a single pair of wires over which a telephone conversation is being carried on at the same time.

A great deal of effort has been and is continuing to be devoted to the perfecting of satisfactory mechanical central office switching systems to care for the extremely complex traffic conditions of the great cities. This work has resulted in the development and introduction of mechanical switching systems by means of which the manifold requirements of large metropolitan areas, such as New York and Chicago, have been successfully met. Hundreds of thousands of lines are now equipped and a continuing program of new installations of a similar character is under way.

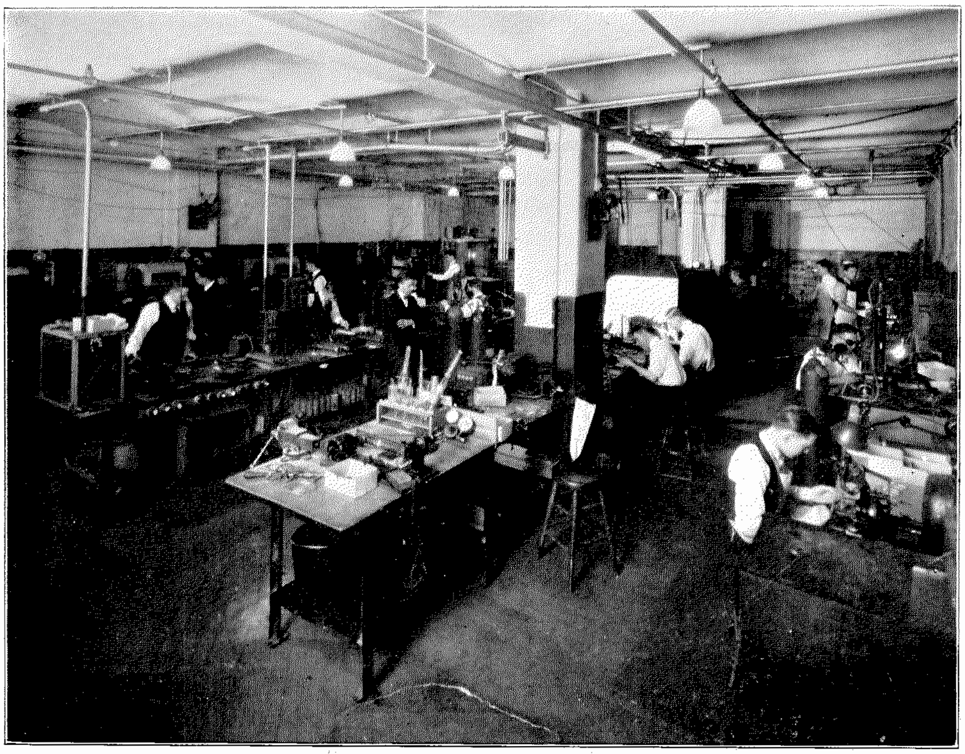
Study of another kind of switching and signalling problem has resulted in the production of selecting apparatus for railway train dispatching purposes which permits a dispatcher at a central point to put himself into immediate communication with any one of a large number of local stations along the section of the line for which he is responsible.

A similar system has been applied to the control and operation of the apparatus of power distribution networks. This system permits either the control of a number of switches or other apparatus located at a single point, such as a large power substation, or the apparatus to be controlled may be located at many points throughout the system, such as individual feeder circuits or small substations. By means of this system, the condition of the power control equipment at many distant points is automatically reported to a central point and through its use the so-called automatic power substation is made a thoroughly practical and reliable innovation.

Out of the results of the work of the laboratories directed toward the major problems of telephone and telegraph communication, arise many interesting by-products which often have valuable applications in other fields. As an example, in the study of telephone quality previously referred to, it was found necessary to devise an instrument for measuring with great precision the sensitivity of the ear to tones of various pitches and intensity. This instrument, which is known as the audiometer, has attracted a great deal of attention from ear specialists to whom it has been shown and bids fair to provide a valuable instrument for the study of defective hearing. In this same connection a knowledge of the characteristics of precision types of transmitters and receivers together with vacuum tube amplifiers has made possible the production of apparatus for the



Experimental Radio Broadcasting Station



One of the Vacuum Tube Research Laboratories aid of those whose hearing is defective, and makes possible the correction of hearing deficiencies far beyond anything that has previously been considered possible.

The oscillograph evolved from the familiar Braun tube has found a place in the study of high frequency currents of the character employed in telephonic transmission. In this type of oscillograph the inertia of its moving element, a stream of electrons instead of the ordinary coil and mirror, is so small that it may be made to accurately follow frequencies of a million cycles or more.

In most cases a development is undertaken to meet a recognized need. Often, however, a line of investigation is pursued with a view to extending our general scientific knowledge; and such a study sometimes bears fruit where least expected. Experiments with transmitters of the greatest possible faithfulness of reproduction, regardless of sensitiveness or efficiency, became of great importance with the sudden development of radio broadcasting and public address systems. A scientific investigation of the so-called "piezo-electric effect"—the characteristic of certain crystals of generating an electromotive force, sometimes of several hundred volts, through the proper application of a mechanical movement—is developing interesting possibilities. Studies started some years ago, on the magnetic properties of certain nickel-iron alloys, are now bringing about revolutionary changes in submarine cable construction and operation, and promise equally important advances in other directions.

Many of the developments that have thus been briefly referred to have been the subject of previous contributions to this Journal and it is to be hoped that many similar contributions are to follow.

Consideration of these more outstanding developments does not, of course, give any picture of the vast amount of detail work which is done every day in the preparation of information and specifications to permit the manufacture of the various products of the Western Electric Company. All those familiar with the problems of large scale production of intricate apparatus can appreciate the magnitude of this task.

Neither can it picture the steady improvement and refinement in quality and reliability of standard equipment which has contributed a large share to the progress of the telephone art in America.

In many ways the organization is unique, in that its efforts are directed toward the production of devices and systems not primarily for sale but for use. Its objective is the production of systems and equipments and materials which will render the most economical and effective service throughout their useful life. This may often mean that a more expensive rather than a cheaper device, so far as first cost is concerned, will be employed, or a higher grade material used than might be considered if such factors as maintenance and repairs and freedom from operating irregularities were not considered in arriving at a conclusion which is to meet the test of the above formula. Thus it is possible to apply the same scientific and engineering methods to the practical application and use of the products, as were employed in their original conception and development. This means in the last analysis that so far as human frailties will permit, those finally chosen are the ones that are fundamentally best qualified to meet the requirements of the service to be rendered, and the choice is made without regard to many of the artificial considerations that must be taken into account if mere salability is the criterion by which the product is to be judged.

The Bell System Research Laboratories have been honored by visits from many of our readers, but for those who have not yet made the pilgrimage, the accompanying photographs will serve to give some idea of the physical appearance of the institution which is dedicated to the development of the art of Electrical Communication.

British Broadcasting

By H. M. PEASE

Managing Director, Western Electric Company, Ltd.

THE close of the year 1923 witnessed the establishment of broadcasting in Great Britain on probably sounder lines than in any other country. The successful introduction of this new industry, however, has required the solution of many difficult problems, and the marked progress which has already been made may be attributed largely to the early adoption of the basic plan that,

1. There should be but a single broadcasting company, whose profits would be controlled by the Government.

2. The individuals or companies who benefit by broadcasting, that is, the listeners-in and the manufacturers, should contribute toward the cost of the service, the former by license fees and the latter by a tariff on the sales of receiving sets.

It will be of interest to review briefly the more important steps which have been taken in the organization of the company, the adoption of uniform license fees and tariffs, some of the engineering problems presented for solution and plans for the future.

Although the main conditions under which a Broadcasting Company or Companies would be allowed to operate were outlined by the Postmaster-General in May, 1922, considerable work was necessary in co-ordinating the varying individual interests of the several manufacturers and the contract whereby a broadcasting authority was set up was not signed until January 18, 1923; broadcast programmes, however, being officially commenced on November 18, 1922. This authority known as the British Broadcasting Company (B.B.C.) has a membership of over 800 manufacturers, six of the larger firms guaranteeing the working capital of the company and also guaranteeing that a satisfactory service would be given from eight stations over a period of two years. The original agreement stipulated that a listening-in license would be issued only to users of wireless sets approved by the Postmaster-General and stamped with the seal of the British Broadcasting Company, that half of the license fee of 10/– and in addition an agreed royalty on each set from each manufacturer should be paid to the Company.

From the beginning, broadcasting proved of the greatest interest to the public; it was soon found, however, that foreign made parts for wireless sets were being imported in large quantities and many people began to make their own sets, finding this more interesting and economical than purchasing a set of an approved pattern. Since the licenses granted by the Postmaster-General were restricted to those listeners-in who had purchased approved sets and to bona fide experimenters, the spring of 1923 found the majority of listeners-in enjoying the broadcast programs without license. Being unable to find a solution to the problem which was satisfactory to the Broadcasting Company and its opponents, the Postmaster-General appointed a Parliamentary Committee to consider broadcasting in all its aspects with special reference to the contracts and licenses which had been or might be granted.

The report of this Committee, which was published in September, 1923, recommended that the existing service of the British Broadcasting Company should be continued and extended for two years upon modified terms, that one form of license at a fee of 10/– a year should be issued and that the license should not give the British manufacturers any protection whatever. Inasmuch as these recommendations conflicted with the British Broadcasting Company's agreement, the Postmaster-General, Sir Laming Worthington-Evans, found it impossible to put the recommendations in force until the agreement expired, and therefore suggested a compromise which was agreed to by the Broadcasting Company and which cleared up the trouble with the so-called "pirates."

This compromise made it possible for persons in possession of unlicensed apparatus to purchase special interim licenses at a fee of 15/– to cover their equipment. A constructor's license at an annual fee of 15/– was also provided for, it being specified that the constructor must buy parts from members of the Broadcasting Company. It was also agreed to pay the Broadcasting Company 12/6d out of the 15/– payable for the constructor's and interim licenses and 7/6d instead of 5/– out of the 10/– payable for a B.B.C. license. The Broadcasting Company in turn agreed to reduce the royalties on the sale of sets by approximately 50 per cent. This proposed system of licensing will be continued until the end of 1924, and it has been further agreed that, providing the Company fulfill the conditions specified, no other broadcasting service will be licensed in the interim period up to December 31, 1924.

A description of the Birmingham station, which is representative of the general type installed, appears in this issue of ELECTRICAL COMMUNICATION, its equipment, as well as the speech input equipment in use at the Birmingham, Manchester, Glasgow and Newcastle stations and the apparatus used exclusively by the Broadcasting Company for the transmission of opera, music and speeches from points outside to the broadcast stations, being supplied by the Western Electric Company, Ltd.

One of the most difficult of the various engineering problems presented for solution arose in connection with the first attempt to transmit speech and music to all the British stations simultaneously. Preliminary tests in the spring of 1923 between London and Birmingham (110 miles) and between London and Glasgow (400 miles), employing open wire trunk lines in conjunction with unloaded terminating cables, indicated that a satisfactory quality of transmission was possible with either music or speech, and, on May 13, 1923, speech was delivered from London to each station by land line and then simultaneously broadcasted from London, Newcastle, Glasgow, Manchester, Birmingham and Cardiff; No. 1 Public Address Systems being employed to ensure sufficient energy at each of the broadcasting stations. While the results of this test were satisfactory from a broadcasting viewpoint, considerable trouble was experienced by cross-talk to adjacent lines.

TABLE I

BRITISH BROADCASTING STATIONS

Station	Call Letters	Old Wave-length (Metres)	Present Wave-length (Metres)	Antenna Input (Watts)	Antenna Current (Amps.)	H. T. Volts	Valves	
							Oscillators	Modulators
London	2LO	363	365	900	10	10,000	1 MT7B	3 MT7B
Manchester	2ZY	370	375	1,000	13	5,000	1 Mullard Silica	2 Mullard Silica
Birmingham	5IT	425	475	500	6.5	1,600	2 No. 212A	2 No. 212A
Newcastle	5NO	400	400	1,100	12	10,000	1 MT7B	2 MT7B
Cardiff	5WA	353	350	1,100	9	10,000	1 MT7B	2 MT7B
Glasgow	5SC	415	420	1,100	13	10,000	1 MT7B	2 MT7B
Aberdeen	2BD	495	495	1,100	8.5	10,000	1 MT7B	2 MT7B
Bournemouth	6BM	385	385	1,100	8.5	10,000	1 MT7B	2 MT7B

NOTE:—All the stations use the Choke-Control system of modulation. The MT7B 5 K.W. valve is manufactured by the Marconi Osram Company. The Mullard Silica 2.5 K.W. valve by the Mullard Valve Company. The 212A 500 watt valve by the Western Electric Company, Ltd.

The new licenses became available early in October and the Postmaster-General announced in November that 298,000 new licenses were granted during October, making the total number of licenses issued up to that time 492,000. It appears now that the Broadcasting Company is assured of a steady and substantial income for the future.

Considerable progress has been made during the past year, eight main stations having been established, the important features of which are listed in Table I. A main station is also proposed for Belfast and relay stations will be established in different parts of the country so that crystal sets may be used more extensively. One relay station is already in successful operation at Sheffield.

Transmitting Stations
British Broadcasting Company

Selection of circuits which were uniform from both transmission and cross-talk standpoints and reduction of power to the minimum necessary to ensure reliable and satisfactory operation at the broadcasting stations did not clear up the trouble and it was only after special precautions had been taken to maintain the earth unbalances of the circuits at a low value that satisfactory results were obtained.

A second problem was that of equalizing the lines. As is well known, transmission by land line involves greater attenuation of high frequency than low frequency currents. In the case of music, a frequency band of the order of 16 to 10,000 cycles is involved. Whereas differences in the efficiency of transmission for different frequencies may not be serious in the case of commercial speech owing to the comparatively narrow band of frequencies involved, such differences in the case of music transmission may assume considerable importance. Provision, therefore, has to be made to obtain uniform transmission at all frequencies, requiring the insertion in the line of suitable net works or equalizers where the trunk lines connecting the various broadcasting centers involve sections of cable. These engineering difficulties have in large measure been cleared up.

An arrangement has now been made between the B.B.Co. and the Post Office by which the B.B.Co. has the use of a trunk line from London to each of the broadcasting stations (except Aberdeen which has a direct line from Glasgow) between the hours of 6 P.M. and 6 A.M. By this means it is possible for any part of a programme to be broadcast simultaneously from any one or all of the stations. For instance, it may happen that the Newcastle programme is being broadcast from Newcastle, Manchester, Glasgow and Aberdeen, while the London programme is being broadcast from London, Bournemouth, Birmingham and Cardiff. As a matter of regular routine, the "News Bulletin" is read in London and is broadcast simultaneously from all stations.

There seems to be no doubt that simultaneous broadcasting is a very valuable aid to the Broadcasting Company, both from economic considerations and also from an interest point of view, and that this facility will assume considerable importance in the future.

A recent development in connection with radio transmission of music from theaters is of interest.

The historic theater, "Old Vic," is so situated with respect to the London Broadcasting Station as to render it difficult to establish a suitable wire connection. The Broadcasting Company's engineers, therefore, installed a small radio transmitting set in the theater. This transmitting set operated on a very short wavelength and the programme was sent to the main transmitting station by means of this short radio link. It was then successfully re-radiated from the main transmitting station. The first regular transmission of this kind took place on Saturday, November 24th, when the first act of the opera, "La Traviata," was thus broadcast.

It has been the aim of the Broadcasting Company from its beginning to select programmes that would be of interest to all, opera and song; jazz music and classical music; weather reports and wireless hints; talks on theology and tips from the stables; children's stories and scientific lectures; chats on puddings and lingerie; commerce and Shakespeare; in fact all of the multitudinous variety of themes that interest the people have been broadcast for the Nation's consumption. Not the least significant feature of the programmes has been the great attention devoted to instructional lectures, the officials of the Company having recognized the immense educational possibilities of broadcasting and have sought and obtained easily the services of experts in every branch of life.

Another important recent development has been the issue by the Company of a weekly publication called the *Radio Times* which, in addition to giving the coming week's programmes at all stations, contains short articles which are of interest to radio enthusiasts and outlines, to a certain extent, the general policies of the Company.

The British public understands that broadcasting has come to stay, recognizes the immense possibilities of this new development in its national life and asks that these possibilities shall be realized in the most beneficial form. It is the aim of the Company that these requests may be adequately met.

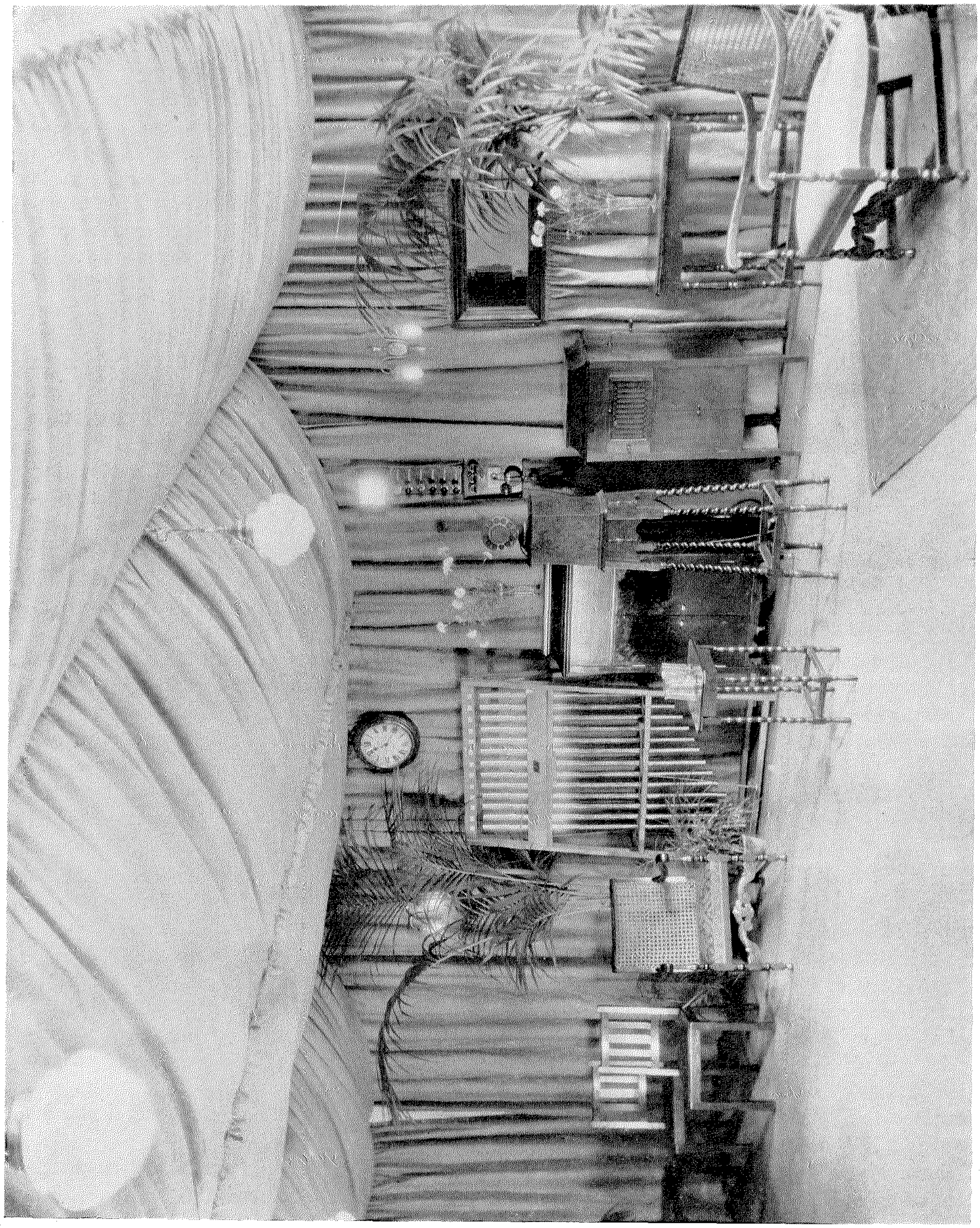


Figure 1—Birmingham Broadcasting Station—The Studio

The Birmingham Broadcasting Station

By A. E. THOMPSON

European Engineering Department, International Western Electric Company

WHEN broadcasting was first mooted in Great Britain, not a few people were sceptical regarding the future of this latest development of the radio art. As if to demonstrate, at the outset, the services which it could render to the community, "5IT," the Birmingham Station of the British Broadcasting Company, during its first transmission announced the results of the Parliamentary elections as they were telephoned direct from the various news agencies on the 15th November, 1922. "5IT" came as a distinct surprise to most listeners; the quality of its transmissions due mainly to its high grade microphone transmitters, being superior to anything that had previously been heard in Great Britain.

For a period of nine months the station was temporarily located at Witton, about three miles from the centre of the city, and it was removed to its present, more central, position on the 11th August, 1923. The removal, which involved the complete dismantling of the equipment and fresh adjustments when again set up, was carried out in less than 20 hours. The work was commenced immediately after the regular evening programme from Witton had concluded at 10.30 P.M., and at 6 P.M. the next day the well known call sign was heard as usual; but this time from a new home.

The station is equipped with the Western Electric Company's No. 101-A Radio Telephone Broadcasting Set. The transmitting gear is housed in a small building specially erected for the purpose in the grounds of the Birmingham Corporation's Summer Lane Power Station, where two high smoke stacks serve to support the antenna. The Studio and general offices are in New Street, Birmingham's most important thoroughfare, approximately a mile distant from the transmitting station, the Studio being connected to the transmitter house by an underground cable containing 7 pairs of 20 pound conductors, (19 B&S gauge).

Studio

The Birmingham Studio is approximately 30 ft. by 20 ft. in area with its floor carpeted and the walls and ceiling artistically draped, with a mauve material of sack-cloth texture, in order to eliminate echo effects. It contains the microphone transmitter, together with its associated amplifier, a grand piano, organ, cabinet gramophone, tubular bells, and jazz band outfit. There is, in addition, a low wooden platform, 3 ft. square, upon which the singer, or elocutionist, is required to stand. This has been found desirable as the artistes are accustomed to standing upon a hard wooden floor; it furthermore definitely locates the artiste before the microphone and prevents those with a dramatic tendency from moving about the Studio.

Upon a wall panel is mounted the transmitter jack and switch, a telephone, to facilitate liaison between Studio and control room, and a series of coloured lamps for indicating the following:—"All correct," "Come closer," "Move Back," "Rearrange," "Wait," and "Speak." Calls to the telephone are made by a flash lamp in the Studio, and by buzzer signals in the control room. When the microphone is "on the air," a large red lamp is lighted.

Adjoining the Studio are the Station Director's offices, the control room (with a window to enable the monitoring operator to see into the Studio), a reception room, where the artistes are received and made to feel at home, and store room for the orchestra's music, etc.

The Microphone Transmitters

The transmitter is the most important link in the chain of transformations which the speech and music have to undergo before being finally reproduced in the listener's receiver. Any slight distortion introduced here will be amplified many thousand times, and seriously impair the quality of the radio transmission.

In ordinary telephone practice the transmitter is required only to respond to voice frequencies of the order of 200-2000 cycles per second, whereas for broadcasting the requirements are much more severe. The piano covers a range of 27 to 4225 cycles per second, while the lowest note of the organ is 16 cycles, and the highest note of the piccolo 4752 cycles per second.

Figure 2—Transmitter and Housing

The high quality transmitter, in regular service at Birmingham, is an air damped, stretched diaphragm condenser transmitter, and is undoubtedly unsurpassed for its high quality of transmission. A thin steel diaphragm, stretched in order to give it a high natural frequency, constitutes one plate of the condenser, while the other is a rigid disc; the dielectric being a film of air one thousandth of an inch in thickness. The high natural frequency of the diaphragm, in conjunction with air damping, results in a transmitter which can be relied upon to give a very high grade of reproduction. It has been possible to obtain good results with speech at distances of 30 to 50 feet away from the transmitter.

On account of the extremely small capacity and high impedance of the transmitter, it is desirable that the first amplifier should be located within a distance of about 6 ft., in order that the connecting leads shall have low capacity, and be free from the effects of electro-

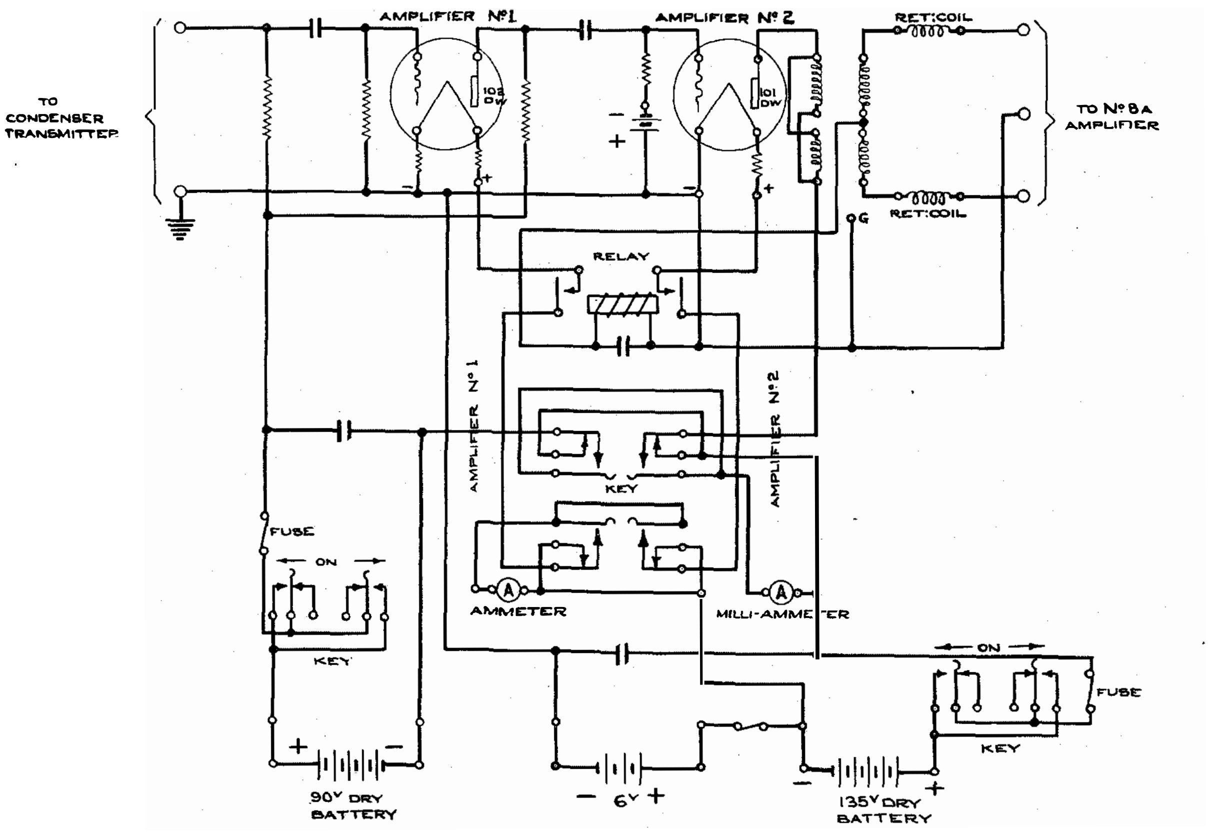


Figure 3—Amplifier for Condenser Transmitter-Circuit

static and electro-magnetic induction to which they would otherwise be susceptible. The transmitter is supported by springs in a metal housing, to minimise the effect of any mechanical vibrations, and a cord and plug serves to connect it to the first amplifier which is located in the Studio.

Condenser Transmitter Amplifier

This is a two-stage amplifier, with resistance-capacity coupling between stages. On account of the high impedance of the condenser transmitter (its capacity is of the order of 400 mmf.) no input transformer is employed, the transmitter being connected directly to the grid of the first tube through a blocking condenser. A high resistance unit is shunted across the grid-filament terminals to maintain the grid of the first tube at a constant negative potential, and the grid of the second tube is given a suitable negative bias by a 9 volt battery. To facilitate the checking of the tube characteristics, and the condition of the batteries, a key is provided, together with an ammeter for filament current, and a milliammeter for plate current measurement.

The amplifier is mounted in a polished mahogany cabinet, in order that it may harmonise with the rest of the Studio furniture, and the filament and plate batteries are contained in metal trays in the lower compartment, which is fitted with doors. The cover of the cabinet is hinged at the rear, and the amplifier panel may be raised into a vertical position for inspection or repairs. A 12 ft. output cord enables the amplifier to be moved about the Studio when a larger radius of action is required. This cord connects it to the input of the No. 8-A amplifier, to be described later.

The No. 373-W Carbon Transmitter

As a standby, a spare microphone transmitter of the well known carbon granular type, as used in the Western Electric Public Address System, is immediately available. This is also a high quality transmitter and has a stretched diaphragm of duralumin, with two carbon buttons one on each side of the diaphragm.

It employs what is termed the "push-pull" principle, and although it will not give quite the same high grade reproduction as the condenser transmitter, its output volume is greater. Therefore, it does not require the two-stage amplifier described above, and is connected directly to the input terminals of the No. 8-A amplifier.

Control Apparatus

The very feeble currents produced by the microphone transmitters require considerable amplification before being delivered to the radio transmitter. For this purpose a three-stage speech input amplifier is provided which has been carefully designed to give equal amplification of all the important frequencies. This amplifier is mounted upon an angle iron framework, five feet high, and is located in the control room adjacent to the Studio. The secondary winding of its input transformer is shunted by a high resistance, and a two-position switch determines the potential applied to the grid of the first tube. The second and third stages are reactance-capacity coupled.

The monitoring device, for securing fine control of output, is a potentiometer shunted across the grid circuit of the second tube. Its resistance is 500,000 ohms and connections are brought out to twelve switch contacts to enable the "gain" to be varied in steps of three miles.

The tubes in the first two stages are of the well known Western Electric 102-D type. Their filaments are in series, and they are controlled by a common rheostat. These tubes are of the coated filament type having relatively low power consumption, and have an average life of the order of 10,000 hours. The third stage employs a No. 205-B, 5 watt tube.

A 12 volt battery is required to heat the filaments, and a dry battery provides the 130 volt plate supply. Three ammeters, reading 100 m.a., 5 m.a., and 4 amperes respectively, are mounted above the amplifier, and test jacks with two plug-ended cords are provided to insert these meters in the desired circuit.

The output terminals are connected direct to the "music lines" in the underground cable leading to the radio transmitter house, and a loud speaking receiver is bridged across these terminals as a check on the quality.

Figure 4--Amplifier for Condenser Transmitter-Cabinet

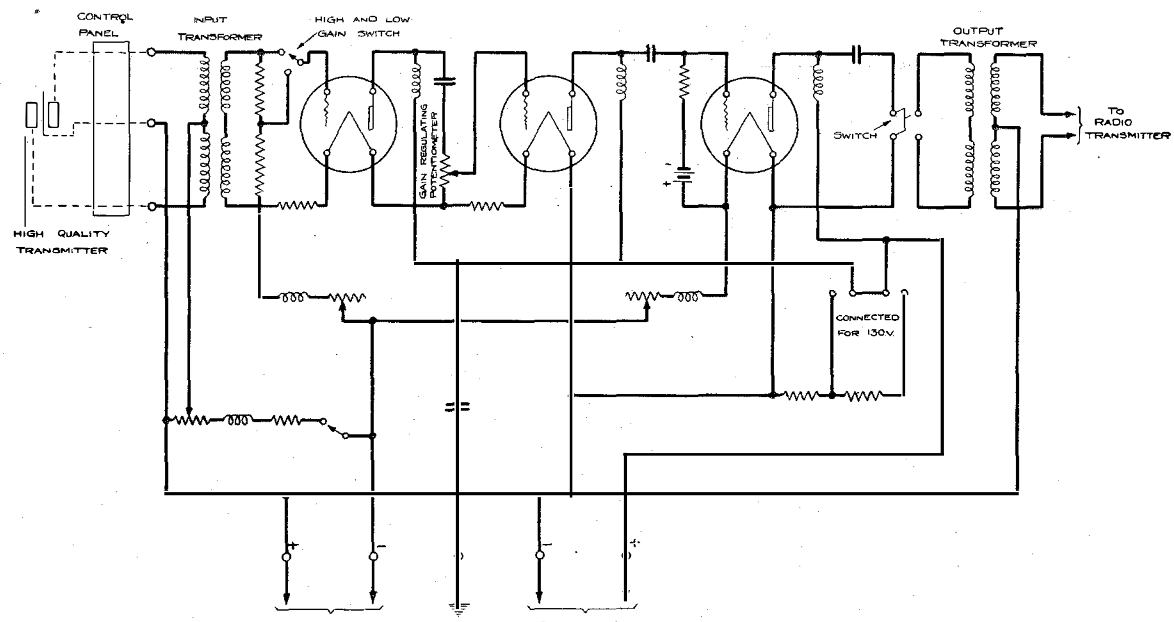


Figure 5—Speech Input Amplifier-Circuit

Control Panel

This panel is mounted immediately below the No. 8-A amplifier. It carries fuses and the various keys necessary for closing the filament and plate circuits of the amplifier and the radio receiver. A special key is provided to enable the operator to change over instantly from one microphone transmitter to another.

Control Operator

The control operator is largely responsible for the success of the broadcast transmission, as it is his duty to make all volume adjustments during the rendering of a selection, as well as to ensure that the artistes are correctly located before the microphone. In making the adjustments essential in maintaining constant volume for different artistes, bands, and choruses, etc., the operator depends mainly upon the volume indicator.

The Volume Indicator

This unit is mounted below the control panel and is bridged across the output terminals of the No. 8-A amplifier. It consists of a vacuum tube rectifier of such high impedance that it causes negligible loss, or impedance irregularity, in the output of the amplifier. A sensitive D.C. meter is connected in the output circuit of the rectifier tube so that the varying alternating current potentials due to speech and music will cause the meter needle to move rapidly back and forth. As these variations will occur over

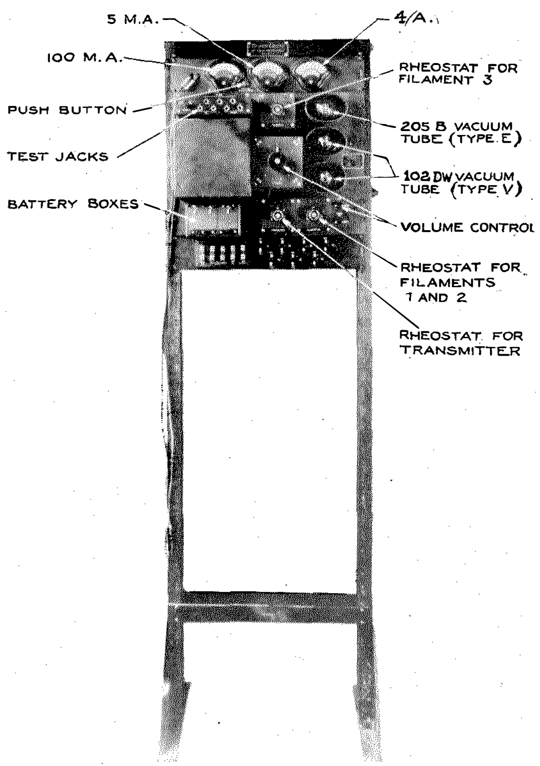


Figure 6—Speech Input Amplifier

a wide range, a given periodic needle-throw is selected, which experience has shown to indicate the reading beyond which overloading of the transmitter tubes will occur.

Additional equipment in the control room comprises a battery charging panel, switch panel, for controlling the Studio signalling lamps, a No. 2-C radio receiver, and telephones for communicating with both the Studio and the transmitter house.

Transmitter House

The radio transmitting equipment is located in a small two-room building almost midway between the two stacks supporting the antenna. The power room is 15 ft. by 10 ft. in area and contains two motor generator sets (one as a standby) mounted on raised concrete bases.

The usual motor starters are mounted on the wall, and all leads from the motor generator sets are taken to a switchboard where facilities are provided for controlling the 16 volt and 1600 volt supply to the power panel in the transmitting room, as well as the supply from the power panel to the field of the high tension generator.

Two sources of commercial supply from different city power plants are available, the supply being 440 volts D.C. in each case.

The Motor Generator Set

The power for the radio transmitter is obtained from a direct coupled motor-generator set comprising a 5 H.P. driving motor (speed 1750 r.p.m.) a high voltage generator and a low voltage generator.

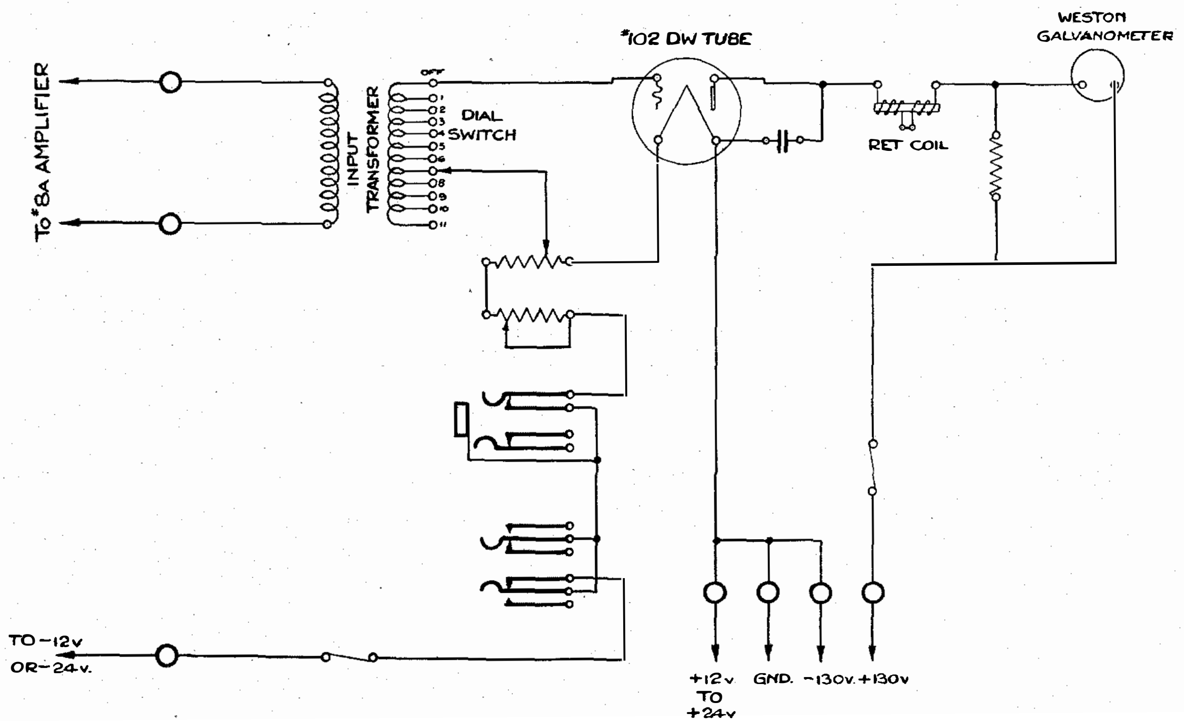


Figure 7—Volume Indicator

The high voltage generator is a direct current, separately excited machine with two commutators, and delivers approximately one ampere, at 1600 volts, to the plate circuits of the transmitting tubes.

The low voltage generator is a D.C. shunt wound machine and is self-excited. It delivers a filament supply of 28 amperes at 14.3 volts, as well as current for exciting the field of the high voltage generator. Voltage control is provided by a field rheostat mounted on the power panel. Both of these generators are so designed as to reduce to a minimum any commutator noise which might introduce disturbance into the transmissions.

Transmitting Room

In the transmitting room are located the power panel, radio transmitter, antenna-earth switch, and antenna lead-in, etc. Suitable accommodation for spare parts and tools is provided as well as a telephone for communicating with the distant control room, and a radio receiver.

The Power Switchboard and Control Panel

The control panel is described as "dead front." This means that although the handles of the switches, and rheostats, etc., appear on the front, all the current carrying parts are mounted at the rear of the slate panels in order to protect the operator from accidental contacts. The rear of the control panel is completely enclosed by a metal cabinet, the door of which may be locked.

Two field rheostats, one for the high voltage, and one for the low voltage generator, are so arranged that once the correct adjustment is obtained it is only required to use one control to regulate simultaneously the voltage of both machines. A circuit-breaker is included in the mains of the high voltage supply and operates on an overload of 25%.

At the top of the panel are two voltmeters, one for indicating the potential across the filament circuit of the tubes, and the other the potential of the high voltage generator supplying the plates. Lastly there are three switches to control the field circuit of the high voltage generator, the plate current supply, and the filament current supply.

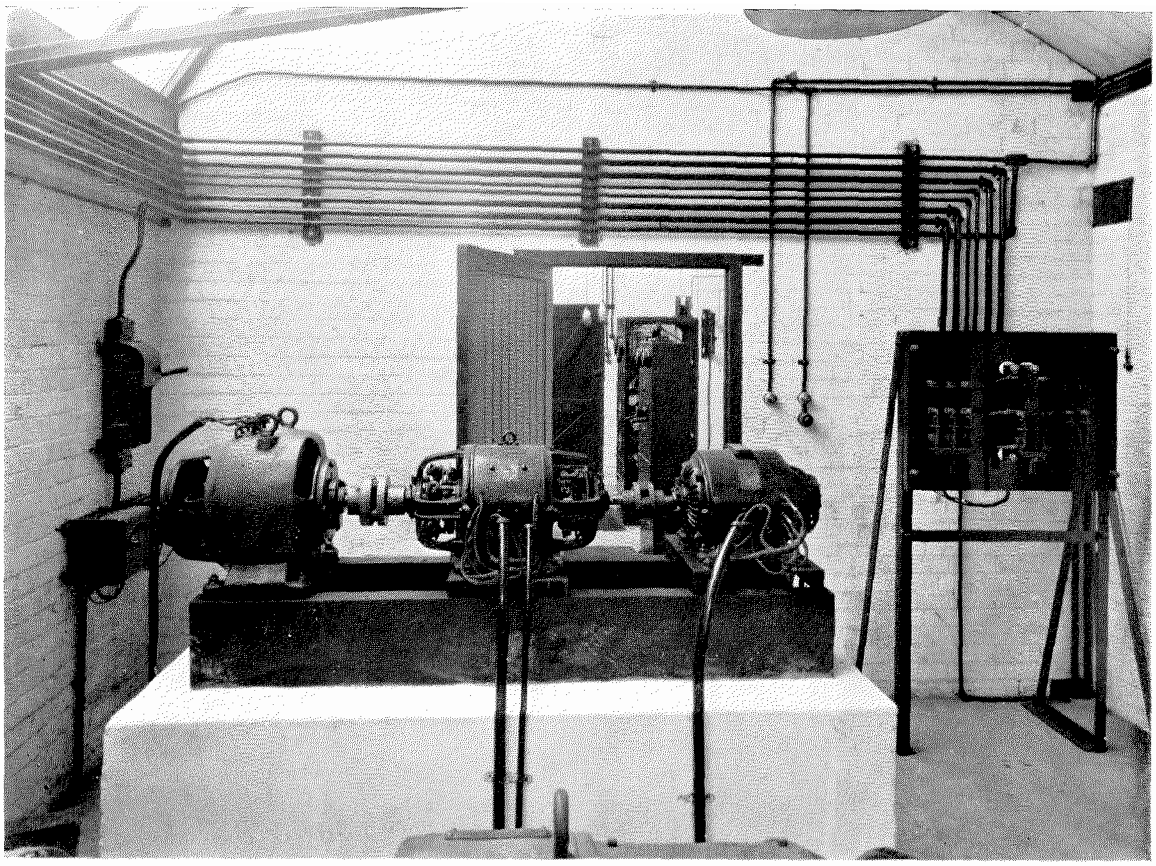


Figure 8—Power Room

The Radio Transmitter

The transmitter panel contains the coils, condensers, vacuum tubes, and other auxiliary apparatus required in order to generate and modulate the radio frequency energy, and is enclosed by detachable expanded metal guards. Four ammeters are mounted upon the front insulating panel. These indicate the antenna current, oscillator plate current, modulator plate current, and oscillator grid current.

power expenditure, and operate at a dull red heat.

The frequency of the radiated carrier wave is controlled by a variometer, the rotor of which serves also to vary the coupling between the antenna, and the plate and grid circuits of the oscillator tubes.

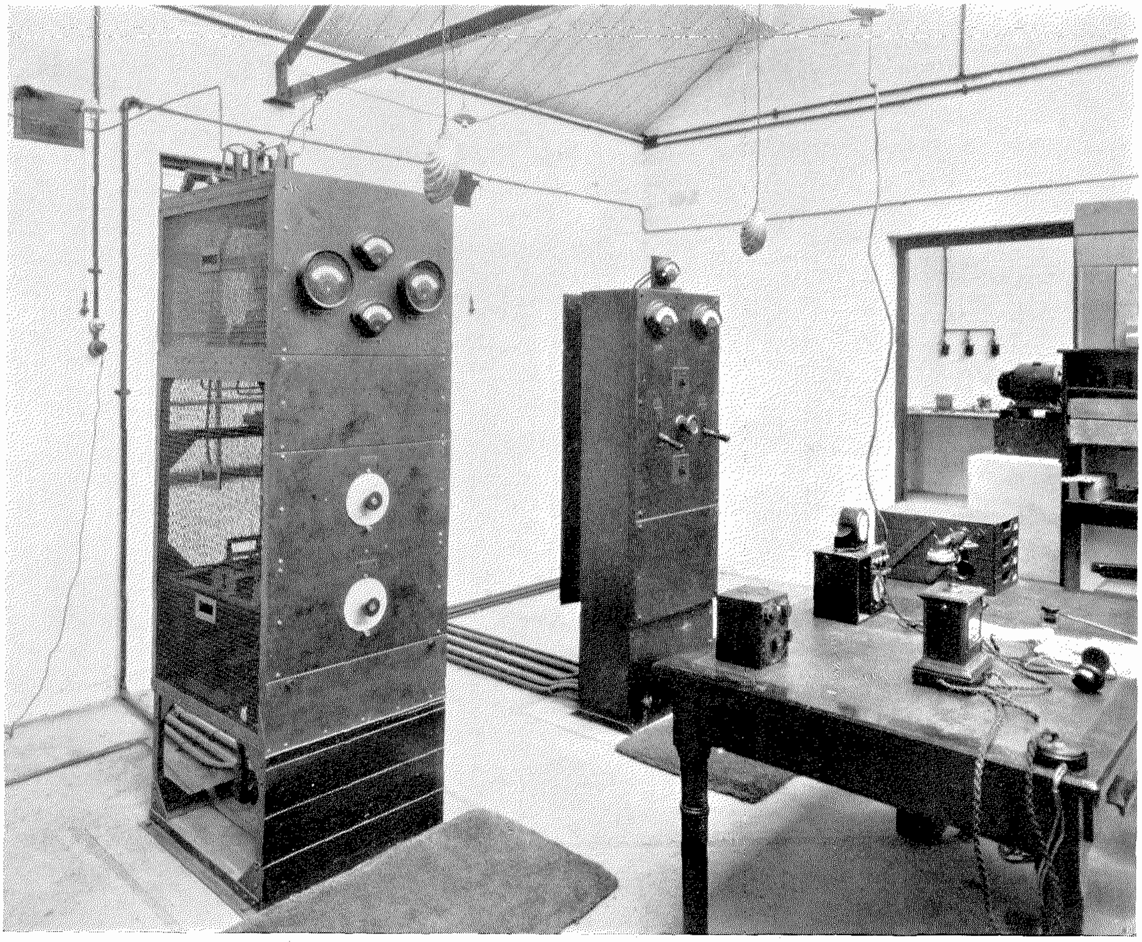


Figure 9—Transmitting Room

Two No. 212-A 250 watt tubes in parallel act as oscillators, and two as modulators, while a No. 211-A 50 watt tube serves further to amplify the output of the No. 8-A speech input amplifier before it is impressed upon the grids of the modulator tubes. The tube ratings are in terms of the high frequency power they can deliver to the external circuit. All of these tubes have oxide coated filaments, ensuring the maximum electron emission with the minimum filament

The oscillator plate circuit is adjusted by means of a variable condenser and two fixed condensers, which may be strapped in parallel with it, in conjunction with tappings on the plate circuit coil, the oscillator grid coil also being provided with taps.

A time-delay relay ensures that no damage will occur in the event of the plate circuit being closed before the filament circuit. This relay is operated by the filament current and is so adjusted that the current must flow through its windings for a period of 20 seconds before its contacts close, and so apply the full plate potential to the tubes. A suitable filter is included in the plate supply mains to eliminate any commutator noise.

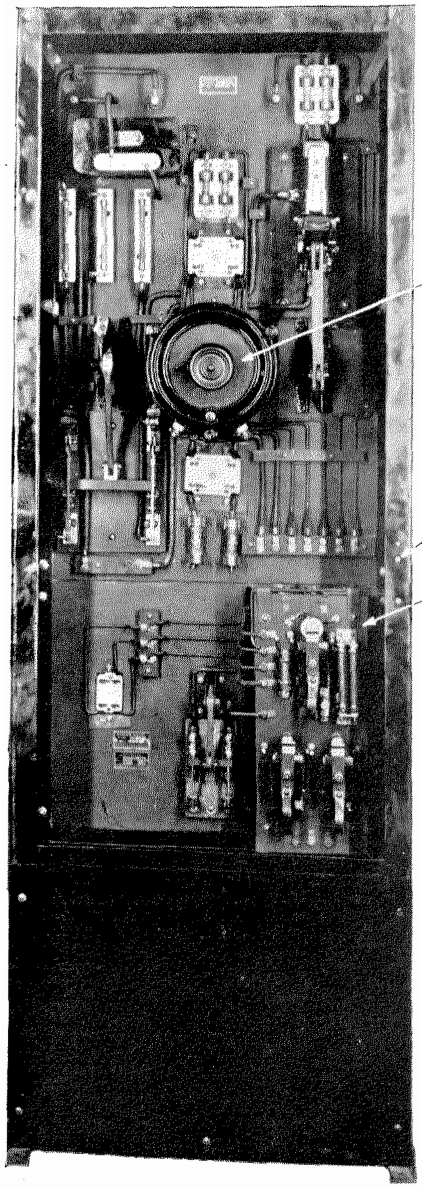


Figure 10—Power Panel

Modulation

The system of modulation used is the well known "Constant Current" system, developed in America by R. A. Heising, and sometimes referred to in Great Britain as the "Choke Control" system. This system ensures perfect modulation and the highest efficiency.

A simplified schematic drawing, in which only one oscillator and one modulator is shown, illustrates the general principle of this system of modulation.

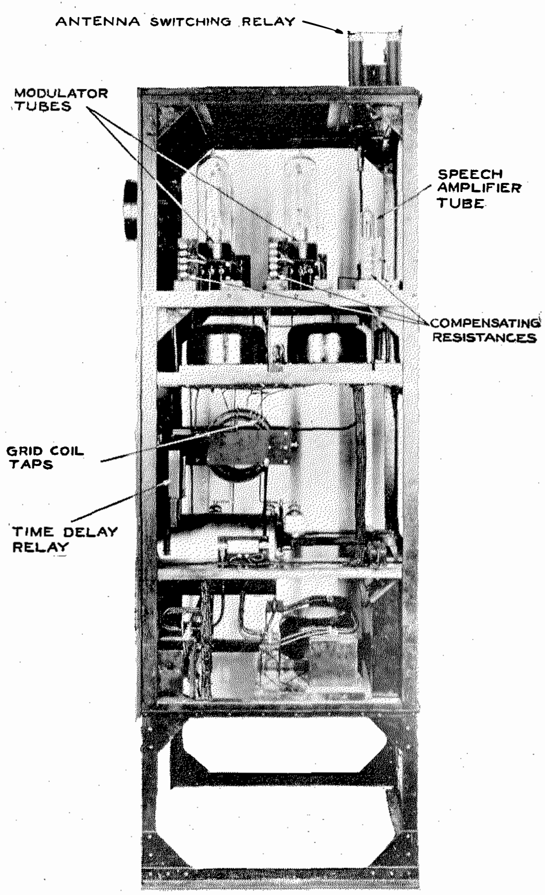


Figure 11—Radio Transmitter

The operation is briefly as follows:—

A source of high potential supply is fed to the plates of the oscillator and modulator tubes through an iron core choke coil, of high inductance, known as the "Speech Choke."

The antenna receives energy from the tuned plate circuit of the oscillator tube and in turn stimulates the grid of the oscillator in such a manner that continuous oscillations are set up.

When varying speech potentials are applied through the input transformer to the grid of the modulator, there will be a corresponding variation in modulator plate current.

The impedance of the "Speech Choke" is such that, no matter how the plate current of either tube may vary, the current supply will remain practically constant. As the modulator tube is shunted across the oscillator, any changes in its plate current will therefore cause corresponding changes in the amplitude of the oscillator plate currents, and thus in the output to the antenna.

The conditions of grid and plate voltage under which the oscillator tube operates are

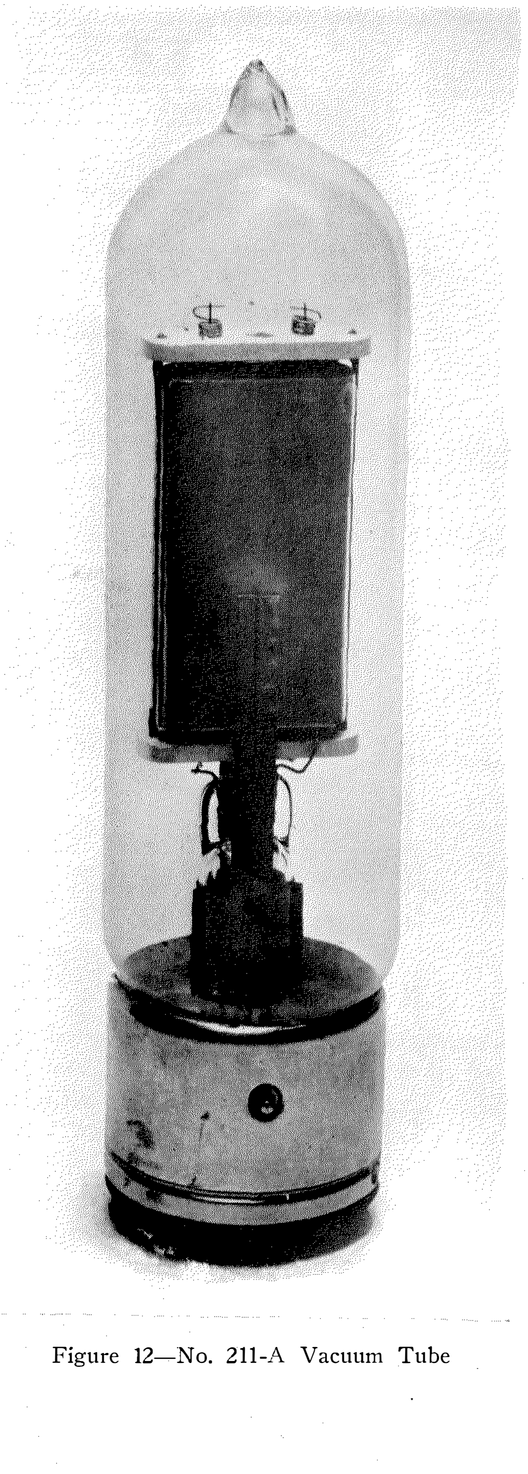


Figure 12—No. 211-A Vacuum Tube

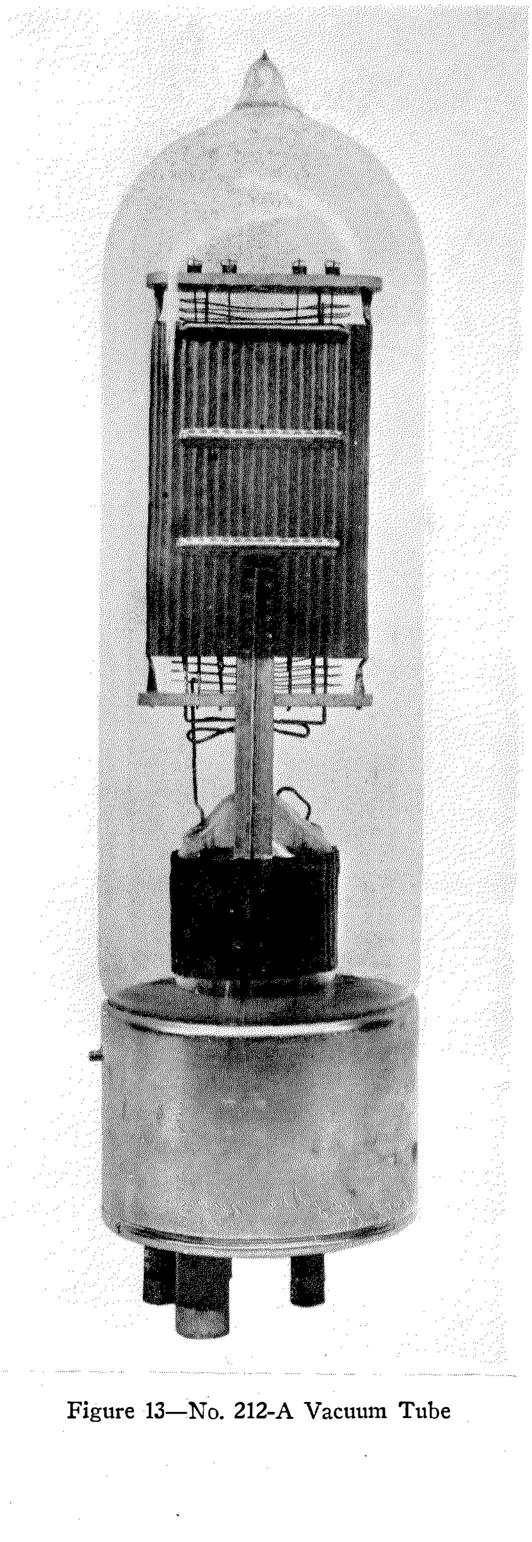


Figure 13—No. 212-A Vacuum Tube

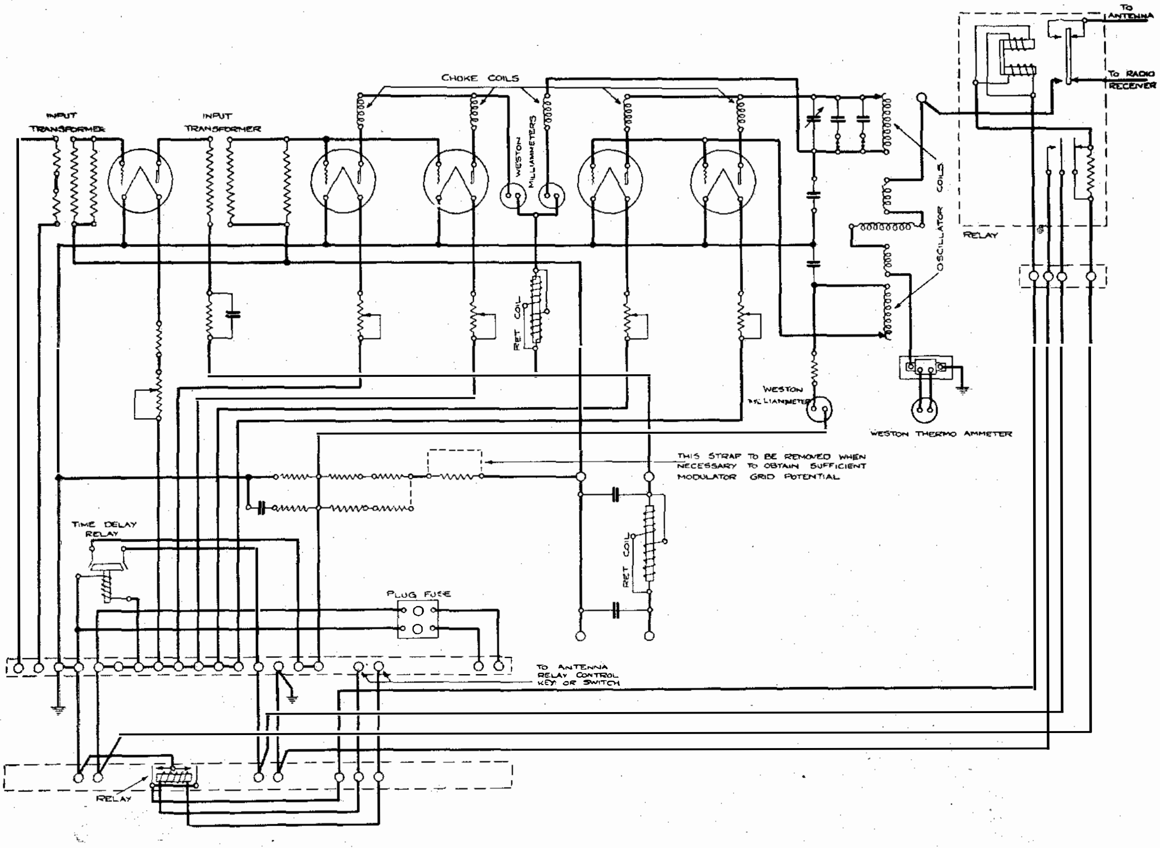


Figure 14—Radio Transmitter Circuit Diagram

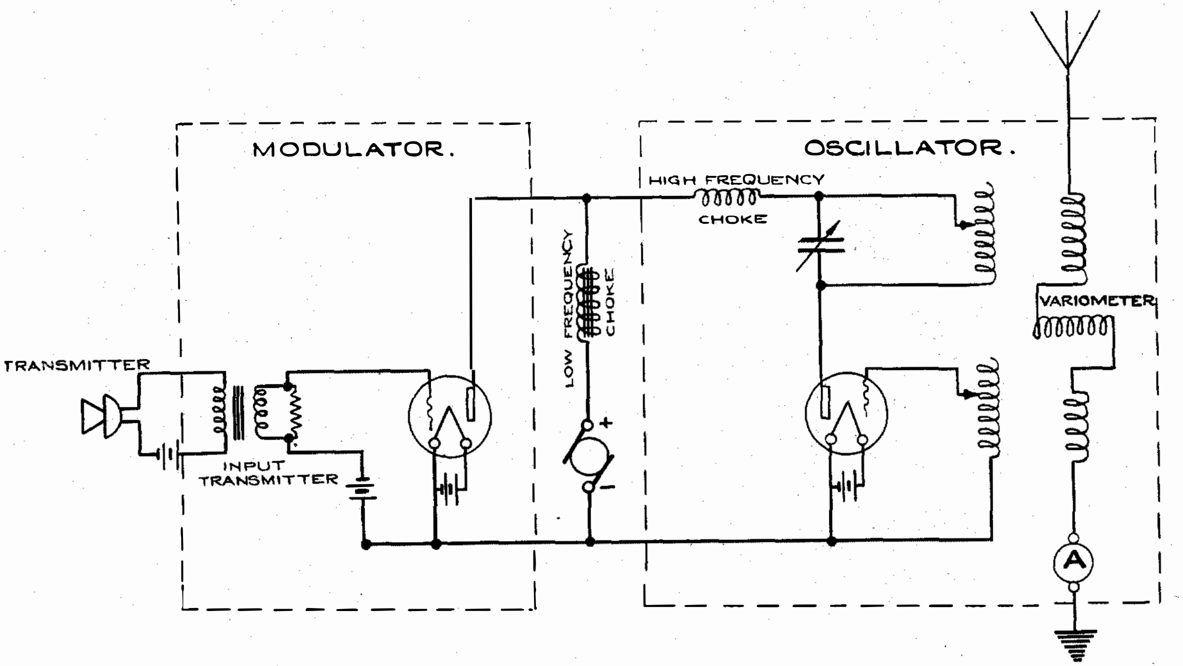


Figure 15—Schematic of "Constant Current" System

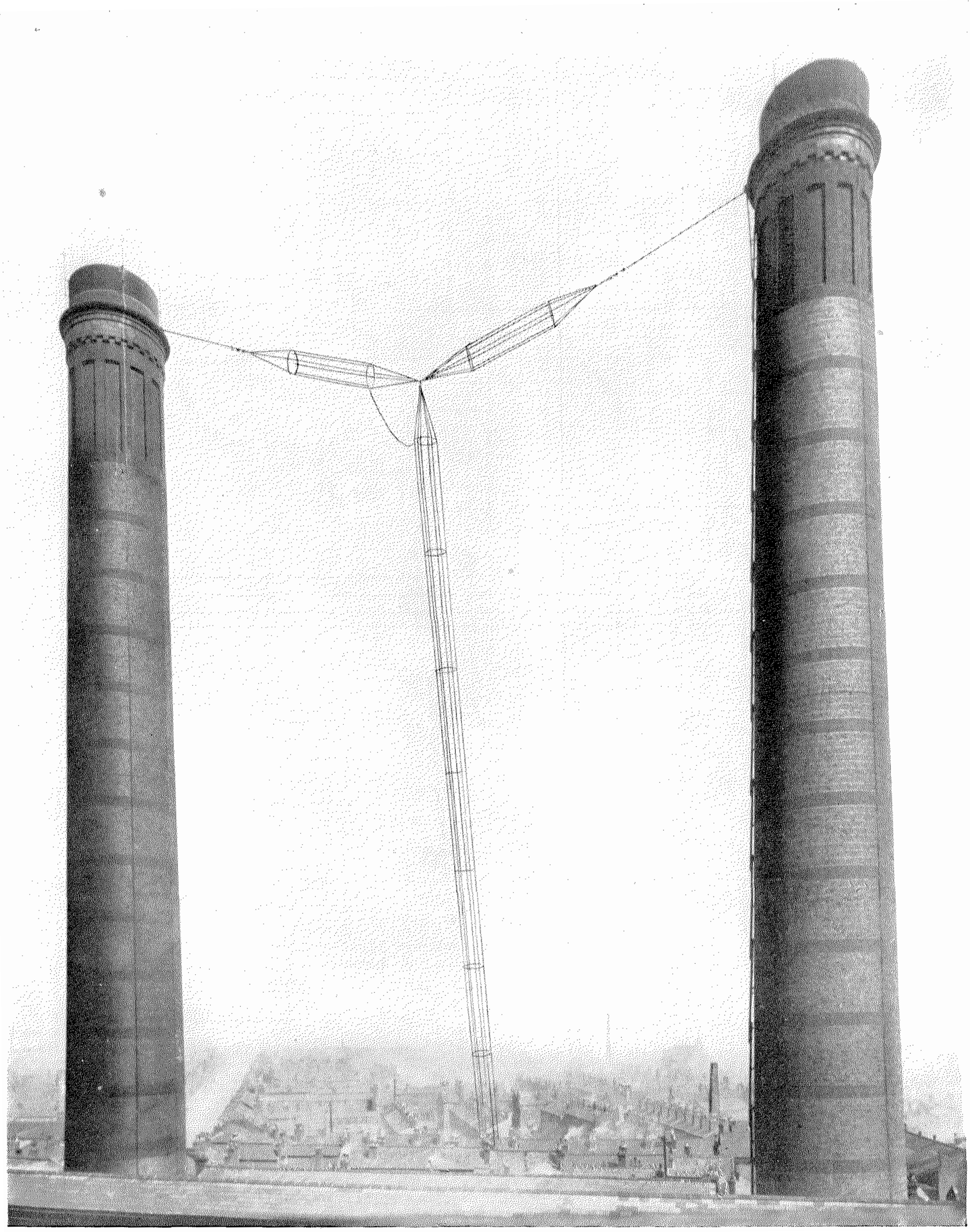


Figure 16—Antenna System

such that the radio frequency currents generated will rise periodically to nearly twice the normal amplitude existing when the microphone is not active.

It will be noted that a radio-frequency choke coil is inserted between the oscillator and modulator tubes in order to prevent the radio frequency oscillations from passing back into the modulator.

The Antenna System

The T shaped antenna is of the "cage" type, composed of six phosphor bronze wires evenly spaced round duralumin hoops, 4 feet in diameter, located approximately every 20 feet.

antenna, and to operate at any desired frequency between 500 and 1000 kilocycles assuming that the antenna has a capacity to ground of the order of 1000 micro-microfarads.

The carrier-wave frequency allotted to the Birmingham Station is 631.5 kilocycles (475 metres).

The daylight range is conservatively rated at 100 miles, based upon the assumption that the receiving equipment employs a vacuum tube detector and two stages of low frequency amplification, but the numerous reports received from listeners indicate that the station has been heard over considerably greater distances.

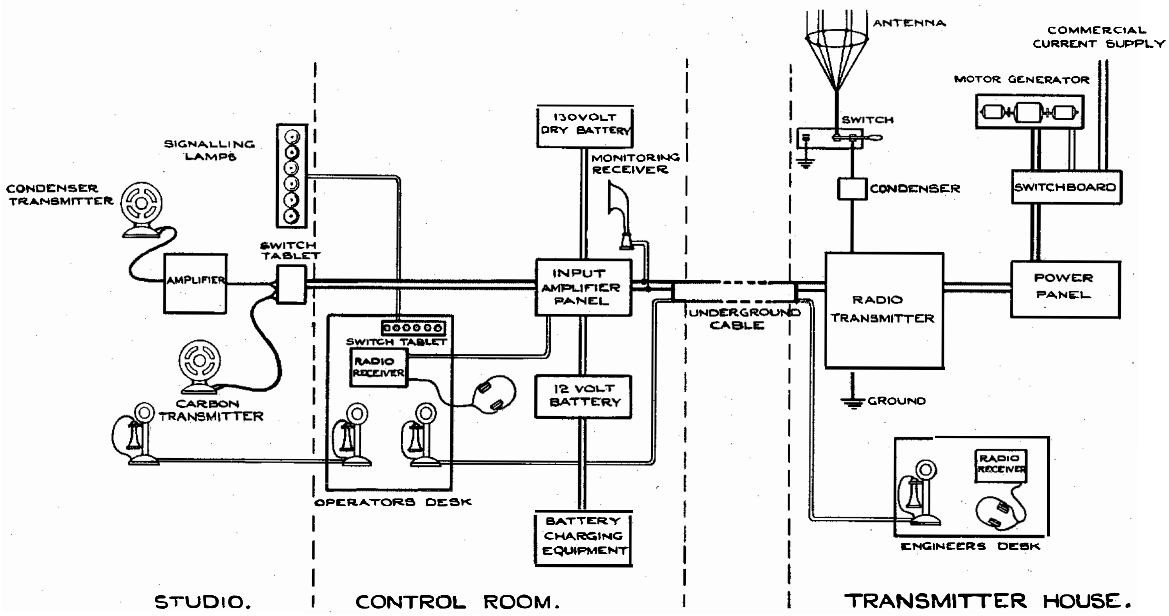


Figure 17—General Plan of Connections

The antenna is 210 feet high, with a horizontal top 100 feet in length, and is supported on pulleys attached to wrought iron bands at the top of two 230 feet smoke stacks, 150 feet apart. The steel cables for hoisting the antenna are secured to hand winches at the bottom of each stack.

To prevent the antenna swaying, and thereby causing a variation in its capacity to ground, it is strained back to a wall and a short lead-in connects it to the transmitter house.

Wavelength and Range

The radio transmitter is designed to deliver 500 watts of radio frequency power to the

Programmes

The Birmingham Station transmits regularly on week-days from 3.30 P.M. to 4.30 P.M. and from 5.30 P.M. to 10.30 P.M., and on Sundays from 8.30 P.M. to 10.00 P.M.

The afternoon transmissions are mainly for the benefit of the trade. 5.30 P.M. to 6 P.M. is "Women's Corner" when papers on dress and cookery subjects, etc., are read.

During the "Children's Corner," 6 P.M. to 6.45 P.M., the staff become Uncles and Aunts, and entertain their tiny listeners with humourous back-chat, fairy stories, etc.

The concerts which commence at 7.30 P. M.

are arranged to appeal to a distinctive class of listeners.

On Mondays an operatic programme is rendered, mainly by members of the British National Opera Company; on Tuesdays, there is dance music or a concert party; Wednesdays, choral music, and a land line transmission from a Picture theatre which has a particularly good orchestra; Thursdays, request items; Fridays, classical music rendered by the Station orchestra of 14 players; and Saturdays, a military band, etc.

Every Sunday evening there is a lecture by a well known cleric, together with sacred and classical music.

For a short period each evening all the provincial broadcasting stations are connected to London by long distance telephone lines, so that news bulletins, specially prepared by the important news agencies, may be broadcast simultaneously by all the stations in the kingdom.

A weather report also is broadcast. This covers Birmingham and the neighbouring counties, and is prepared by the Meteorological Department of the British Air Ministry.

The Origin and Development of the Transmission Equation

By R. APPLEYARD

European Engineering Department, International Western Electric Company

IT seems a proper mode of approach to the study of telephony to trace if possible the way in which its principles have been developed from the far older and wider groupings of the arts and sciences comprised in natural philosophy and mathematics. Although telephony, as we know it, has not yet completed a half-century of existence, the theory of speech-transmission has extended to such proportions that in this brief review it is only possible to select for examination a single representative feature. Let us, therefore, restrict ourselves to an attempt to identify the track through the wilderness of theory, experiment, and calculation, along which have come to us our transmission equations.

For this purpose, though it is convenient to write down certain expressions to exhibit their forms, if their origin is stated it will be unnecessary here to enter into detailed discussion of the mathematical devices by which they have been established, for we are concerned only with the broad features of their history. As an objective, first observe the familiar relationship (1) for the current C_x at the receiving end of a cable of length x, when C_o is the current, and V_o the voltage, at the sending end, i.e.,

$$C_x = C_o \frac{e^{Px} + e^{-Px}}{2} - \frac{V_o}{Z_o} \frac{e^{Px} - e^{-Px}}{2} \qquad (1)$$

where P and Z_o are characteristics of the cable, each depending upon the four quantities: resistance, capacity, inductance, and leakance, as well as upon "frequency." It is common knowledge that this expression may be derived by reasoning applied to a short element of length of cable, by taking account of the rate of change of potential along it, in terms of resistance and inductance, and the rate of change of current along it, in terms of leakance and capacity, assuming that voltage and current vary in accordance with a sine law. But how did it become possible to treat this kind of problem in this kind of way?

It is scarcely to be expected that the development of this equation can be identified step by step through the ages; there remain, however, definite landmarks, built up from what were more or less stumbling-blocks in the history of our subject. The present purpose is to invite attention to such of these as may serve for guidance.

Telephony has disturbed the coordinates of space and time. Moreover, it has annexed the sciences of acoustics, mathematics, light, heat, mechanics, electricity and magnetism, with the result that to-day it is difficult to dissociate the conditions that fix the limits of speech-transmission from principles and methods of calculation that have their origin far anterior to the achievement of Graham Bell. To introduce Newton, Lagrange, and Fourier into the history of the telephonic transmission equation, and simultaneously to look forward to the conclusion in a year or two of the first half-century of the invention of the Bell Telephone, requires caution to avoid an anachronism; nevertheless, it is the only way in which to bring the salient facts into true perspective.

Newton's immortal work *Philosophiæ Naturalis Principia Mathematics* which was printed in 1686 and published in 1687, treats in its second part of bodies in motion. Section VIII of that part is concerned with the propagation of motion through fluids, and it constitutes the foundation of the theory of the transmission of sound waves. He there gave us the earliest notion of an elastic medium through which pulsations are transmitted by successive condensations and rarefactions constituting spherical waves, he associated the vibration of the sounding body with this motion, he indicated its relation to the laws of the pendulum, and he investigated the propagation of such a motion through a tube. It is also noteworthy that he assumed for the displacements of the air in a sound-wave, a sine law.

The analogy between the motion of waves and the oscillation of water in a U-tube was also discussed by Newton, and to a first degree of approximation he brought into relationship the time of oscillation, the wave-length, and the velocity of propagation. Finally he pointed out that his hypothesis assumed that the particles of water ascended and decended in a straight path, and that in actual waves in water they moved in circles. To the mathematicians of his time, these were new ideas. They had not considered the motions that determine wave-forms; consequently Newton's treatment of the subject was misunderstood. Exactly 200 years later, history repeated itself; for the theory of transmission through telephone lines then enunciated was found difficult to comprehend, and deductions from it were found difficult to accept, by those who had substituted for so long upon ohms, microfarads, and direct currents.

From the *Principia* to the writings of Lagrange is a long stride; but it is justified, for three reasons. Lagrange lifted the problem of wave-transmission into the realm of lucid analysis, he directed attention to the work of Newton, Taylor, the Bernoullis, d'Alembert, and Eulor, and he left behind him writings that must to all time be regarded as one of the most glorious literary achievements of mankind. His avowed object was "To destroy the prejudices of those who still doubt if mathematics will ever be able to convey true light into physics." In his *Oeuvres* will be found an account contributed by him in 1759 to *Miscellanea Taurinensia*, in which is described the "nature and the propagation of sound." It reviews the whole question up to that time, and it illuminates and smoothes every step of a path which had been obscure and irksome to traverse. It must suffice here to observe that at p. 79 of *Tome* I—in the course of his famous analysis of the problem of a vibrating cord loaded at various points, an analysis which he gives in detail because of its general application to transmission problems there occurs the expression

$$P \cdot \frac{c^{Rt}+c^{-Rt}}{2} + \frac{o}{R} \cdot \frac{c^{Rt}-c^{-Rt}}{2} \qquad (2)$$

where c is "the number of which the hyperbolic logarithm is 1." It will suffice to notice merely the form of this relation (2) of terms, its resemblance to that representing to-day the voltage or current in a telephonic transmission line, and the introduction of the exponential or damping term.

There may have been earlier examples of the use of expressions of this form, but as Lagrange describes it as "neuve," it is probably here that we must seek for the origin of our transmission equations. Further it should be remarked that 140 years after Lagrange published this communication, Pupin realized while studying Lord Rayleigh's "Theory of Sound," the significance of the loads added by Lagrange to the catenary, and in his paper (Am. Inst. of Electrical Engineers, Vol. XVI, 1899) he described how he made use of the analysis, by Lagrange, of the free vibrations of a string, fixed at its two ends, and loaded at equidistant points by equal weights.

After the *Oeuvres* of Lagrange, the next conspicuous land-mark in physical science as applied to the problems of transmission, is the work of Fourier. In 1822 he published his treatise on the *Theory of Heat.* He explained that physicists had found the flow of heat along a bar of metal to be logarithmic, i.e., that if one end of such a bar is heated, under conditions designed to avoid disturbing effects, the temperature at any point along the bar, after a sufficient time has elapsed to bring about a stable state, is proportional to the logarithm of the distance of that point from the heated end. To this problem he applied his analysis, and he gave the solution.

$$v = Ae^{-x\sqrt{\frac{2h}{kl}}} + Be^{x\sqrt{\frac{2h}{kl}}} \qquad (3)$$

where v = temperature at distance x from the heated end.

k = Conductivity of the metal for heat.
$2l$ = Length of side of a square bar.
A and B = Constants depending upon limiting conditions.
h = External "conductivity" of the prism (square bar).

It is noteworthy that this equation (3) was derived by him as the integral of

$$\frac{d^2v}{dx^2} = \frac{2h}{kl} v \qquad (4)$$

which he found to represent the conditions of equilibrium of the heated bar.

Lord Kelvin, when he was Sir William Thomson, was inspired by the work of Fourier, and by proceeding to develop a theory of transmission through telegraph cables he arrived at the "Telegraphic Equation." Lord Kelvin, however, does not appear to have extended his researches to telephonic transmission through long cables sufficiently to determine the distance through which speech might be heard in definite cases. This problem was referred to in a paper by the late Lord Rayleigh (3rd Baronet), at Montreal in 1884, as President of the British Association. He said that "the principles of this subject were laid down thirty years since by Thomson, but he (Lord Rayleigh) had not met an application to the circumstances of a cable." He then proceeded to work out an arithmetical example, which so far as can be traced is the first of its kind. He assumed a periodic variation of potential, imposed at one end to be propagated along the line of length x in accordance with the law

$$v = e^{-\sqrt{\frac{n}{2k}}\cdot x} \quad \text{Cos}\left(nt - \sqrt{\frac{n}{2k}}\cdot x\right) \qquad (5)$$

in which $\frac{n}{2\pi}$ is the frequency of the electrical vibration. According to Lord Rayleigh's notation, v is here the amplitude of the received vibration, and k is a constant depending upon the resistance and the capacity. He estimated that for the Atlantic cables of that time, 1884, k could be expressed in C.G.S. measure as 2×10^{16}. It is instructive to observe how he completed his estimate of the distance through which speech might be transmitted.

To assign a value to n, he supposed that a representative note, to be transmitted, had a pitch rather above the middle C, so that $n = 3600$, and $\sqrt{n} = 60$. Then, recognizing $e^{-\sqrt{\frac{n}{2k}}\cdot x}$ as the damping term, operating upon a cosine term, he considered the two cases (i) when the damping is unity, and (ii) when the damping is $\frac{1}{e}$, i.e., when

$$e^{-\sqrt{\frac{n}{2k}}\cdot x} = e^o = 1 \qquad \text{(i)}$$

and when

$$e^{-\sqrt{\frac{n}{2k}}\cdot x} = e^{-1} = \frac{1}{e} \qquad \text{(ii)}$$

Condition (i) thus represents the case when $x = o$, i.e., the beginning of the line at the sending end. Condition (ii) represents the case when $x = \sqrt{\frac{2k}{n}}$. In other words, at the distance $x = \sqrt{\frac{2k}{n}}$ from the sending end, the amplitude would be reduced in the ratio $1 : \frac{1}{e}$ which is $1 : 0.368$. Substituting the value of $k = 2 \times 10^{16}$ and $n = 3600$, corresponding to the selected Atlantic cable, he thus obtained.

$$x = \sqrt{\frac{2k}{n}} = \sqrt{\frac{4 \times 10^{16}}{3600}} = 3.3 \times 10^6 \text{ centimetres.}$$

This is 33 kilometres, or approximately 20 statute miles. His estimate therefore was that a note corresponding to about the middle C would be reduced in amplitude in the ratio $1 : 0.368$ in traversing 20 statute miles of Atlantic cable. In this manner he found that a distance of 20 miles would reduce the intensity of sound "to almost a *tenth*." This at first may seem a little puzzling, for the ratio $1 : 0.368$ is not a *tenth*. The explanation is that the ratio $1 : 0.368$ represents what Lord Rayleigh described as "the reduction in *amplitude* of the electrical vibration." *Intensity* is a different matter. In effect, he assumed that the *intensity* of sound in the telephone is proportional to the square of the amplitude of the electrical vibration, so that the ratio of intensities at the beginning and at 20 statute miles respectively, is $1 : (0.368)^2$ or approximately $1 : 0.1$.

To complete the estimate, he explained that this reduction of intensity could not often be repeated without rendering speech inaudible, and that consequently "with such a cable the practical limit would not be likely to exceed *fifty miles*, more especially as the easy intelligibility of speech required the presence of notes still higher than is supposed in the above numerical example." This example deserves more than passing notice. It illustrates the use of the exponential term as a transmission measurer; it shows how the natural limits 1 and $1/e$ can be employed to simplify the arithmetic and to approach towards a transmission unit; it emphasises the relationship between power in electrical units, and intensity in acoustic results;

it shows how great was the need, from the transmission standpoint, to advance beyond microfarads and ohms; and it indicates that Lord Rayleigh was not an optimist.

Looking back from the vantage ground of present knowledge we can recognize that past difficulties were not merely due to the fact that "practical electricians" were limited to ohms and volts. Telephonic transmission was also delayed because theorists adhered too long and too tenaciously to the telegraphic case of single impulses, as treated by Lord Kelvin. The credit of being the first to subject alternate-current transmission in cables to direct treatment, was in 1907 ascribed by Dr. Drysdale to Professor T. H. Blakesley, who from 1885 to 1904 was on the staff of the Royal Naval College, Greenwich. In confirmation of this it may be remarked that the first edition of Blakesley's pioneer treatise entitled "Alternating Currents of Electricity" appeared in 1885, with its elucidation of the transmission problem, with the application to it of hyperbolic functions, and with a table of those functions appended.

The year 1884 was the beginning of a period of research, criticism, and reform, that may now be recognized as a necessary consequence of the universal desire to secure improved transmission and the organization of lines and systems of communication. Technical men were being invited forward by theorists, and pushed in the same direction by economists. At the British Association meeting that year Lord Rayleigh did not content himself with a statement of the transmission problem, he hinted at the need for technical men to advance generally in knowledge of their own subject, beyond the stage associated with direct currents. He declared that the introduction of powerful alternate current machines by Siemens, Gordon, Ferranti, and others, was "likely to have a salutary effect in educating those so-called practical electricians whose ideas do not easily rise above ohms and volts." The transmission problem was his selected example.

So-called "practical electricians" might have retaliated by complaining of the obscurity and aloofness of the theorists of that time, but they did better than this: they demonstrated by direct achievement that when theorists state their results in a form that lends itself to arithmetic, practical electricians are ready to come into line and to pull their full weight. The controversy was devoid of malice; and as both sides saw the humor of the situation, it was stimulating and beneficial.

Early in March, 1887, Sir William Preece at that time Electrician, and subsequently Engineer-in-Chief to the General Post Office, read a paper before the Royal Society on the limiting distance of speech by telephone. In common with most submarine-telegraph electricians of his day, he had been brought up upon what was called the "K. R." law, as a means of determining the "speed" of a cable or circuit, i.e., the number of words per minute that could be transmitted through it effectively. To use his own words: "It is given by the following equation,

$$a = B\,kr\,l^2$$

B being a constant dependent principally on the units used.

k the inductive capacity per unit length (mile or knot)

r the resistance per unit length, and

l the length in miles or knots."

He explained that a "limits the number of vibrations that can be sent through any circuit. If a be 0.196 second, as it was in the French Atlantic cable of 1869 (2,584 knots long) then it is impossible to send 5.1 currents per second through that cable, but it would be possible to send 5, or 2½ complete reversals, per second. Moreover, as the number of reversals varies inversely with the square of the length, it shows that such a cable if of 100 miles length, would allow 1,562 reversals to pass through it. It is necessary to remark that these expressions involve no mention of e.m.f. or of current, and therefore, the number of reversals which can be produced at the end of a wire is quite independent of the impressed e.m.f. and therefore of the strength of the current."

Sir William Preece lacked neither courage nor facility in assumption. He stated that "the law that determines the distance to which speaking by telephone on land lines is possible is just the same as that which determines the number of currents, which can be transmitted through a submarine cable in a second." His proofs were founded upon facts revealed during his long experience as a practical electrician, and if his logic had been as unassailable there would have been an end to the matter. He explained in the Royal Society communication that the evidence upon which the "K. R." law is based was the result of experiments carried out in 1853 by Mr. Latimer Clark, whose assistant he (Sir William Preece) then was; and he proceeded, "the experiments were made by me in the presence of Faraday; many were his (Faraday's) own; he made them the subject of a Friday-evening discourse at the Royal Institution on January 20, 1854, and they are published in his (Faraday's) Researches, Vol. 3, p. 508. They received full mathematical development by Sir William Thomson in 1855 (Proc. Royal Society, 24th May, 1855) who determined the law, the accuracy of which was proved by Fleeming Jenkin, and by Cromwell Varley; and the 110,000 miles of cable that now (1887) lie at the bottom of the ocean afford a constant proof of their daily working."

Let us recall the remarkable summary given by Faraday of these experiments. They bear closely upon the problem of transmission, and pp. 508 to 523 of the volume of the Researches to which Sir William Preece refers, is still an instructive and fascinating account of the phenomena of "charge" and "discharge." He demonstrates the incompatibility of estimates of the velocity of transmission through wires of different metals and of different lengths by various observers; and he emphasizes the necessity for taking into account the circumstances of the wires "being twined round a frame in a small space, or spread through the air through a large space or adhering to walls, or lying on the ground." At the end of his remarks there is a characteristic note in which he directs attention to an account of still earlier work on the same phenomena as those shown to him by Mr. Latimer Clark, which "has just been brought to my notice." These phenomena are the prior investigations by Werner Siemens of Berlin; the account of them is dated, 1850, and Faraday observes "it is only justice that I should refer to them."

Although the "K. R." law, which ignored inductance and leakance, had been a useful guide to submarine-telegraph electricians when making rough estimates of "speed" of signalling in the design of core for cables in certain restricted cases, there was no justification for assuming that it could be accepted as a general law that would give accurate results, especially in the case of long telegraph cables. The truth is that telegraph engineers, by means of signalling condensers, receiving-condensers, and adjustments of various kinds, were able then as now, by experience and skill, to coax signals through almost any continuous circuit, and they were able, by arranging the terminal conditions, to compensate in considerable measure for delinquencies of the "K. R." law applied to the length of cable. For this reason the limitations of the law in submarine telegraphy had been masked. The assumption that this crude "K. R." law was applicable to cases of transmission in telephony was even more untenable.

Lord Kelvin's early writings on the work of Fourier and on the differential equation which expresses the linear motion of heat in an infinite solid are contained in the *Cambridge Mathematical Journal*, 1841 and 1842. His treatment in the *Philosophical Magazine* in 1853 of the transmission of transient electric currents through linear conductors was a natural and important step. Incidentally he directed attention to the experiments of Weber in 1846, in which the conductor "consisted of a wet string of various lengths, and all the wire of the electro-dynamometer and the ordinary galvanometer." Thus was determined the "Duration," and thus were examined the exponentials, and the oscillatory character of the phenomena. Kelvin subsequently found that the oscillatory discharge had been suggested by Helmholtz (Berlin, 1847) who had deduced the probability partly from consideration of the magnetic effects, and partly from an observation by Wollaston "while attempting to decompose water by electric shocks, that both descriptions of gases are exhibited at both electrodes." The paper by Lord Kelvin contained in the Proceedings of the Royal Society, May, 1855, is well known. It gave the solution of the differential equations of transmission, and it disclosed the "K. R." law.

In 1856, at the British Association meeting at Cheltenham, Mr. Wildman Whitehouse cast some degree of doubt upon the applicability of the "K. R." law to actual service conditions. Lord Kelvin took up the challenge in a periodical called the *Athenæum* and he sought to explain the divergences from the law upon the grounds that "it depends on the nature of the electric operation performed at one extremity of the wire, and on the nature of the test afforded by the indicating instrument at the other, whether or not any approach to the law of squares is to be expected." He even went so near to the full explanation as to state that he thought, it "probable that electro-magnetic induction in the receiving instrument has most sensibly influenced the retardations observed with the shorter lengths of cable, increasing relatively those observed with the shortest."

Mr. Oliver Heaviside, whose contributions to the *Philosophical Magazine* between 1873 and 1881, with regard to transmission through cables, had established his reputation, began in 1882 a series of papers in *The Electrician* which with intervals of interruption continued until about the year 1901. They dealt with electromagnetic theory, and they interpreted the riddle of transmission in a manner that instructed, amazed, or delighted his contemporary electricians, according to their discernment. His perception of the right coordination of the facts, his power and inventive faculty in treating quantitatively whatever subject he might choose for examination, his inexorable logic, and his humor, constituted him in the electrical community a philosopher, a reformer, and a critic of unparalleled originality and poignancy.

The experimental work of David Hughes in 1886 confirmed the truth of the theory of surface conduction "along wires under certain circumstances" which Heaviside had already advanced. This led him to disclose his views relating to the functions of wires and the dielectric surrounding them, and to induction and electric current in round cores, the diffusion of electrical waves into wires, and the propagation of waves along them. The development by Heaviside of the theory of the "distortionless circuit" was an advance of conspicuous importance. His demolition of the "K. R." law as applied to telephony was of equal consequence. Further, our gratitude is due to Heaviside for his insistence that the inductance, corresponding to the inertia, of the circuit in the case of telephony, owing to the rapidity of telephonic changes of current, is not negligible, and may easily be a dominating factor in perfecting speech-transmission.

This sketch, confessedly drawn with a broad pencil on a rough canvas, may serve to indicate in outline the course of events. The task of filling in details and applying to the whole the necessary refinements of light, shade, and color, is facilitated by the circumstance that the subject in its later phases has extensive literature.

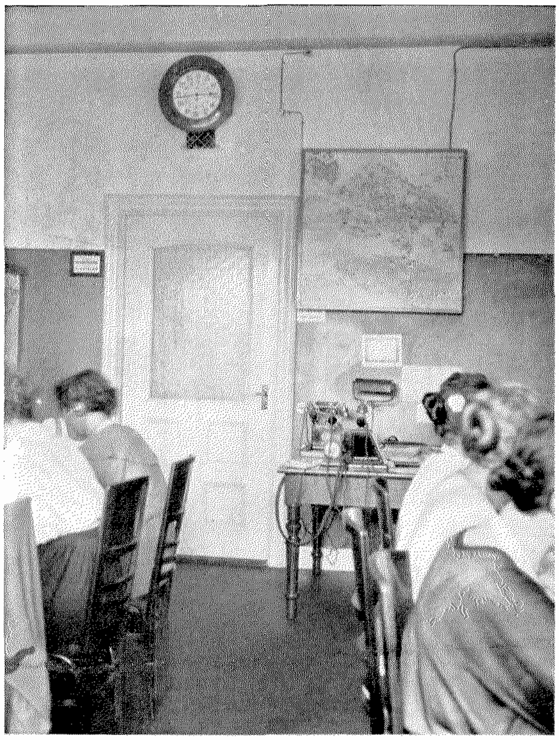
Here, then, we must leave the industry of the pioneers, and of their equation. It was intended to conclude with some account of the brilliant achievements of those who followed in the field. Justice, however, cannot yet be done to them, they are too many, and their work too vast for brief treatment. It must suffice to remark that with a clear view of the relationship of the electrical constants to one another in alternating-current circuits, and with a strong grasp of needs and ways-and-means, they have developed in less than a quarter of a century a new domain of science and industry, extending from cable telephony to radio-telephony—a triumph of measurement, scientific and industrial cooperation, observation, and courage.

The Taxicab Telephone Service in Stockholm

By S. M. CATTERSON

European Engineering Department, International Western Electric Company

ONE of the most interesting of the various special forms of service to which the telephone has been applied is its use as a despatcher of taxicabs. In Stockholm (Sweden), where there is one telephone for every four inhabitants, it is to be expected that the telephone would be used in the ordinary way to call the nearest known office or garage where a cab could be ordered. This method has the obvious disadvantage that the garage may be a considerable distance from the calling subscriber, thus involving loss of time and additional expense owing to the distance involved.



Some years ago a system of providing telephones at the regular taxicab stands throughout the city was put into operation, and, as it has proved very successful, a short description may be of interest.

Briefly stated, the system centralizes the control of all taxicab telephones at one switchboard, to which every call for a taxicab is switched and from which the order is handled directly.

For this purpose, a special switchboard is used, centrally located with respect to the taxicab stands. In the operating room, easily visible to all operators, is mounted a map of Stockholm; this map being equipped with small switchboard lamps, marking the location of each taxicab stand. The whole district of Stockholm is divided into six sections and circuits are provided so that when an operator presses a key, associated with the circuit of any one of these districts, those lamps in the map of the district will be lighted which are associated with the taxicab stands at which cabmen are available for hire; the lamps which do not light indicate that no cabmen are at that time available at those particular stands.

The lighting of the lamps is accomplished in the following manner:

Each of the cabstands has a telephone box directly connected to the special switchboard. Each cabman is provided with a special plug, which he inserts into a jack in the telephone box at his stand and leaves in position whilst waiting for a call. The cabman removes the plug and takes it with him upon receiving instructions to drive to an address. If another cabman is waiting, he, in turn, inserts his plug in the jack vacated by the previous cabman.

The method of operating is as follows:

A caller requiring a taxicab calls on his regular telephone and asks for the taxicab station. He is immediately switched to an operator at the special switchboard, who records his address and name in a book. This operator then depresses the key, associated with the district in which the caller is located, and glances at the map to see the nearest free taxicab. She then calls the taxicab stand indicated and instructs the cabman regarding the address and name of his customer. Meanwhile the caller is waiting on the line and the operator, as soon as the cab has been despatched, advises the caller. If the nearest free taxicab is at a considerable distance from the caller's address, the operator obtains the caller's approval to the despatch of the distant cab. If no free cab is available, the caller is so informed.

To facilitate operating, there are provided on the special switchboards and within easy reading distance of each operator, smaller scale, but otherwise duplicate maps, showing the locations and cabstand numbers corresponding to the large map, and also charts, recording every street in Stockholm, together with the nearest cabstand numbers.

The circuits to the cabstands are one-way signalling, but, in order that the cabmen may be able to call the office, arrangements are made for the receipt of such calls by a special operator. The need for such facilities is apparent for the following reasons:

The cabman has instructions to report cases where no one was found at the address given, and, upon receiving such information, the original record of the call is marked accordingly.

If the cabman is waiting at a stand for a long time without instructions, he calls to ascertain if the line is in operating condition.

If a customer calls at the cabstand and takes a taxicab for a long journey, the cabman first telephones the office and advises it accordingly, so that another taxicab may be sent to take his place at the stand, if desirable.

The cabman has instructions to report immediately if anything has been left in his cab, so that the operator will know, if enquiries are made to the taxicab station.

The number of operators required to maintain an efficient service fluctuates considerably and arrangements are made to hold operators available for emergency service. For regular traffic, during business hours in the winter months, the necessary number of operators varies from three to eight, but during inclement weather conditions the number is increased to sixteen or seventeen.

In this matter of operators, the success of the system largely depends upon the foresight of the supervisor, and it is her duty to keep in touch with public affairs so that special taxicab demands for large meetings and so forth may be adequately cared for. She also periodically calls the meteorological office and obtains weather forecasts.

The number of calls handled is in the order of 100,000 to 150,000 calls per month. Of these less than ten per cent are ineffective calls; that is, no cab has been available for the caller. Such ineffective calls are generally distributed over only three or four days of the month, when, on account of bad weather or for other reasons, there is an exceptional demand for taxicabs. In such cases, many subscribers would call two or three times for a cab and "all calls" are included in the figure given.

There are at present four hundred and twelve taxicabs operating under this system, distributed at sixty-four cabstands. The owners of these cabs are united in a "Society of Taxicab Owners." A taxicab owner may drive one of his cars himself. Membership in the Society is controlled by the existing members. The number of taxicabs maintained by each member is also determined by the Society. The Society negotiates collectively for its members in matters of cabstands, licenses, etc. All rights to ply for hire are granted and controlled by the police and the Society acts on behalf of its members in such matters. The Society pays the accounts rendered by the Telephone Administration for telephone service.

The object of the Taxicab Telephone System is primarily for the convenience of telephone subscribers. The system has been devised and constructed by the Telephone Administration with the object of obtaining increased revenue as the result of an increase in the number of telephone calls put through. The system also tends to increase the popularity of the telephone.

The cost of operation is largely, but not wholly, borne by the Taxicab Society, which pays rent on the basis of:

(a) The number of lines to cabstands from the Taxicab Telephone Station.

(b) An agreed number of trunks from the Taxicab Telephone Station to the regular Telephone Exchanges.

(c) Number of operators at the Taxicab Telephone Station Switchboard and hours worked.

The Taxicab Society pays this rent in return for the additional cab hirings which they get as the result of the telephone system.

The Taxicab Telephone System has proved to be remunerative to the Telephone Administration. The advantage of the system to the Taxicab Society is also considerable, about twenty-five per cent of the taxicab business resulting from this special telephone service. Of this amount of business, some would be lost if there were no Taxicab Call System, and for the rest, the people who now call a taxicab by telephone would find some other means of doing so.

The number of hirings per taxi per day is in the order of 35 and the advantage to the Taxicab Society 4 or 5 hirings per day, which would otherwise be lost.

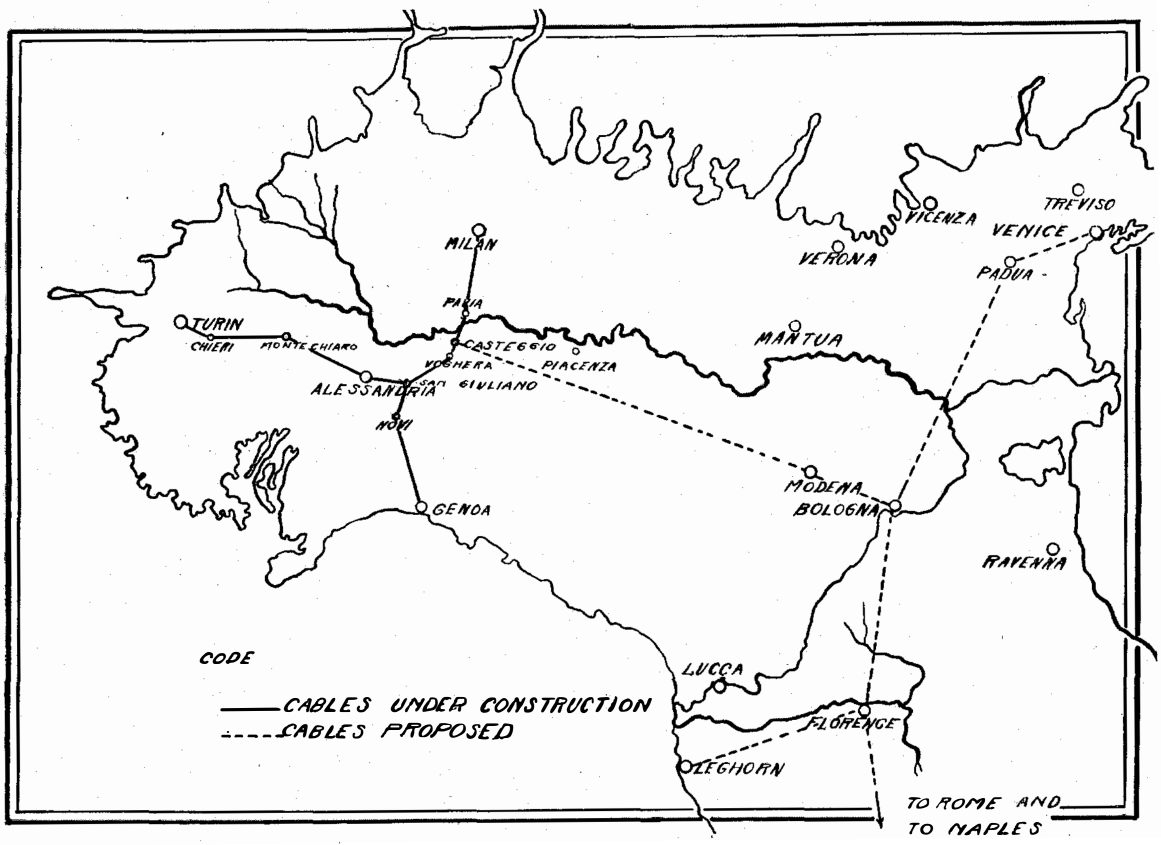
As regards the time it takes to get a taxicab through the Taxicab Call System, this depends upon many variable factors; for example, the distance of the house from the nearest stand, the time of day, weather, etc. In general, however, at times other than the rush hours, a call from a house near the centre of the city takes about thirty seconds and by the time one has arrived in the street, say two minutes later, the cab is there. During the rush hours, one may have to wait two, three, or five minutes, whilst the cab comes from a distant stand.

The Work of Installation of the Underground Telephone Cable—Milan—Turin—Genoa*

By ING. G. MAGAGNINI

Editor, Telegrafi e Telefoni

STARTING from the terminal station at Milan, situated in the Posts, Telegraphs and Telephone Palace, the laying of the first Interurban Telephone Cable in Italy was begun on December 18, 1922, destined to link together Milan-Turin and Genoa.



The course of the cable has the form of a large "Y" with the junction point of the three branches at San Giuliano where a repeater station will be built. The project was studied and plans made in such a manner as to render possible the extension of the Interurban net-work, providing for the connection at Casteggio of a future cable for Bologna, Florence and Naples. The complete project also comprises the net-works Bologna-Venice and Florence-Leghorn; thus, when the plant is finished, as was foreseen by law No. 253 of March 20, 1913, Italy will be supplied with a long uninterrupted cable line which will reach from Turin to Bologna, Florence, Rome, and Naples with branches from San Giuliano to Milano, San Giuliano to Genoa, Bologna to Venice and Florence to Leghorn.

Whether Government or private industry will provide for the other trunks of this basic cable of the national system is not yet known; but in any event it is to be hoped that efforts will be made to develop this most important work in the interests of our country as soon as possible.

The cable is completely underground and runs

* Published in Telegrafi e Telefoni, (Anno IV, No. 3, 1923), by whose courtesy the following translation is permitted.

for obvious reasons of economy, of facility of laying, of maintenance and of security, on a road foundation along the whole route with the exception of a small strip of about 25 kilometers in the proximity of Genoa, where the provincial road is so near to the electric power lines of the Giovi railway and to those of the distributing power company that the telephone cable would have suffered from disturbances due to induction. In this stretch it was necessary to modify the normal route and to pass through secondary valleys or over the crests of the hills. Similar precautions were taken along all the route to

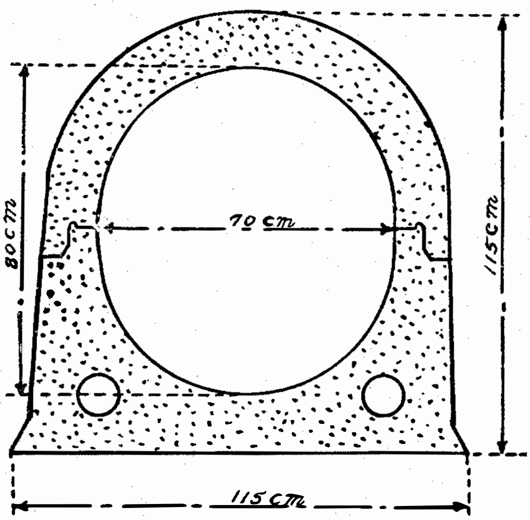


Figure 1

avoid too near approach to power lines and other sources of inductive interference.

The cable is placed in vitrified clay duct in its passage through cities and through inhabited centres in general, in special iron tubing over the numerous bridges and through other constructions which are met with along the route and in terracotta troughing in the ordinary road routes.

Figure 1 shows a section of the terracotta troughing; Figure 2, a plan and section of the manhole of the type employed in the town duct line, its form, however, often being modified in order to avoid the numerous obstacles which are so frequently found in the under-soil of cities; Figure 3 represents a plan and section of the jointing chamber of the type used in passing through the small inhabited centres; and Figure 4, the joint cover used with the ordinary terracotta troughing.

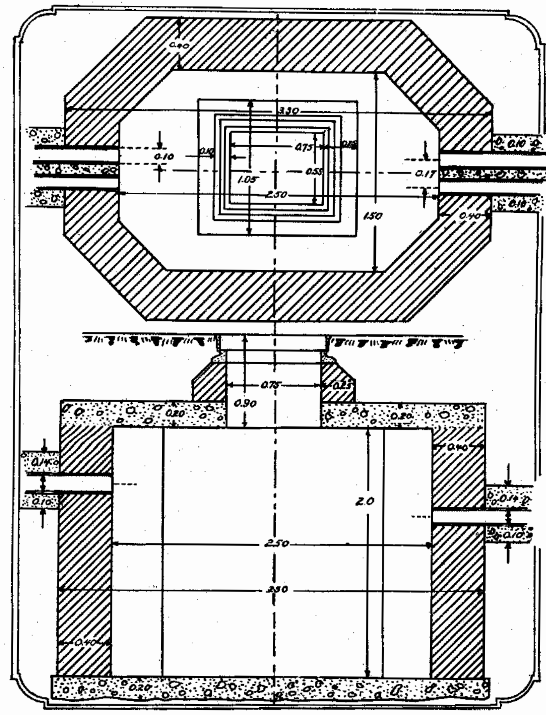


Figure 2

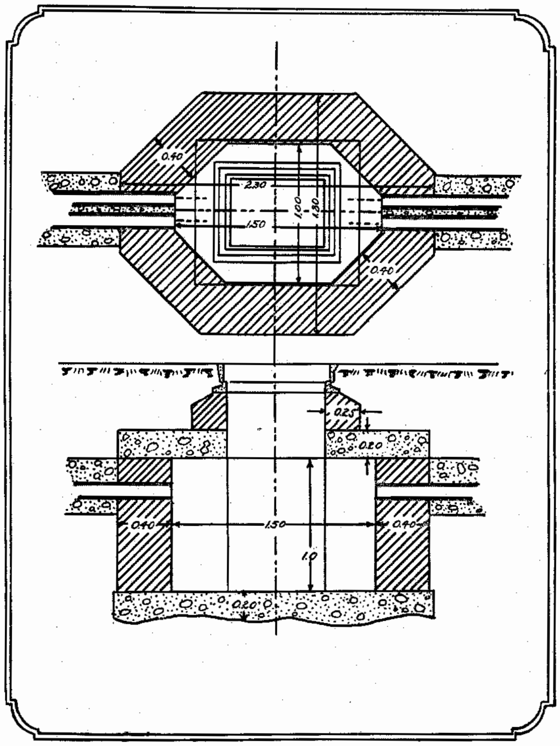


Figure 3

After having chosen the most convenient route, it was necessary on account of the electrical requirements to carry out a complete topographical survey and make accurate measurements. These operations began on April 24, 1922, and were completed on the 25th of September following. The four sections in which the Milan-Turin-Genoa cable is naturally divided have the following lengths:

First Section Milan-Casteggio	64,814 meters
Second Section Casteggio-S. Giuliano	39,539 meters
Third Section San Giuliano-Turin	112,889 meters
Fourth Section San Giuliano-Genoa	78,924 meters
	296,166 meters

Vitrified clay duct was provided in the following localities:

First Section: Milan - Moro di Locate - Pieve Emanuele - Siziano - Ponte Carate - Porta Pescarina - Pavia - Case Nove - Albaredo - Robecco - Pavese-Barbianello-Casteggio.

Second Section: Voghera-Casei Gerola-Castelnuovo Scrivia-Sale.

Third Section: Castelceriolo-Alessandria-Quargnento - Fubine - Montemagno - Grana-Caliano - Montechiaro d'Asti - Castelnuovo d'Asti-Moriondo-Chieri-Torino.

Fourth Section: Pozzolo Formigaro-Novi-Gavi-Voltaggio-Busalla-Pedemonte-Genoa.

The total length of the vitrified clay duct amounts to about 36 kilometers. Special duct for the crossing of the iron bridges, for the masonry bridges and for the roadless zone near Genoa amounts to about 20 kilometers. The balance, which is terracotta troughing, amounts to approximately 240 kilometers.

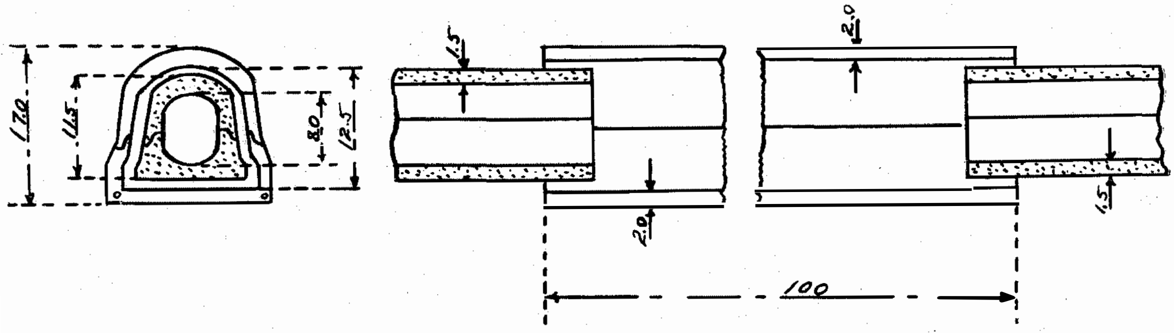


Figure 4

In Milan, a section of an existing urban duct route 1.5 kilometers long was utilized. This comprises 211 meters of 16-way duct, 771 meters of 8-way duct and 408 meters of 6-way duct.

A further 334 meters of 6-way vitrified clay duct, 1975 meters of 4-way and 2372 meters of 2-way were constructed; Figure 5 shows a section of the excavation and the 2-way duct. In addition, just outside the city on the road from Vigentino towards Pavia, 10 kilometers of

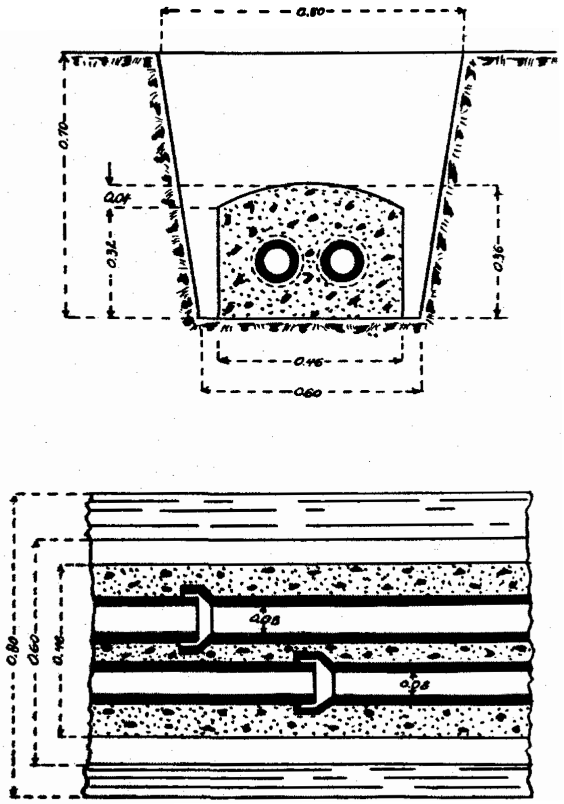


Figure 5

terracotta duct were laid, after which the ordinary troughing was started.

The terracotta duct is of a similar pattern to the vitrified clay used in the urban section, and Figure 6 shows the joint cover used with this type.

The difficulties in the urban and suburban section were considerable on account of the large number of obstacles encountered along the cable route, and on account of the tangle of tubes and pipes of every kind amongst which it was necessary to work. In several places, work of revetment and strengthening of the road was rendered necessary on account of the tramway track.

Immediately outside the inhabited district, and for the whole zone of the low Lombardian Plain as far as the Po, the difficulties did not cease, but only changed in nature. The abundance of water in the sub-soil necessitated the continued use of a means for extracting it from the excavations and rendered the progress of the work considerably slower.

In some stretches of the route, the road is flanked by canals, the water levels of which are higher than the bottom of the trench, manholes and jointing chambers, so that water oozed from the walls and from the bottom of the excavations. The jointing chambers and manholes all had to be constructed in such a manner as to avoid the infiltration of the sub-soil waters. The external and internal walls were lined with waterproof cement and it was necessary to employ caissons of iron sheeting where the external water was under heavy pressure.

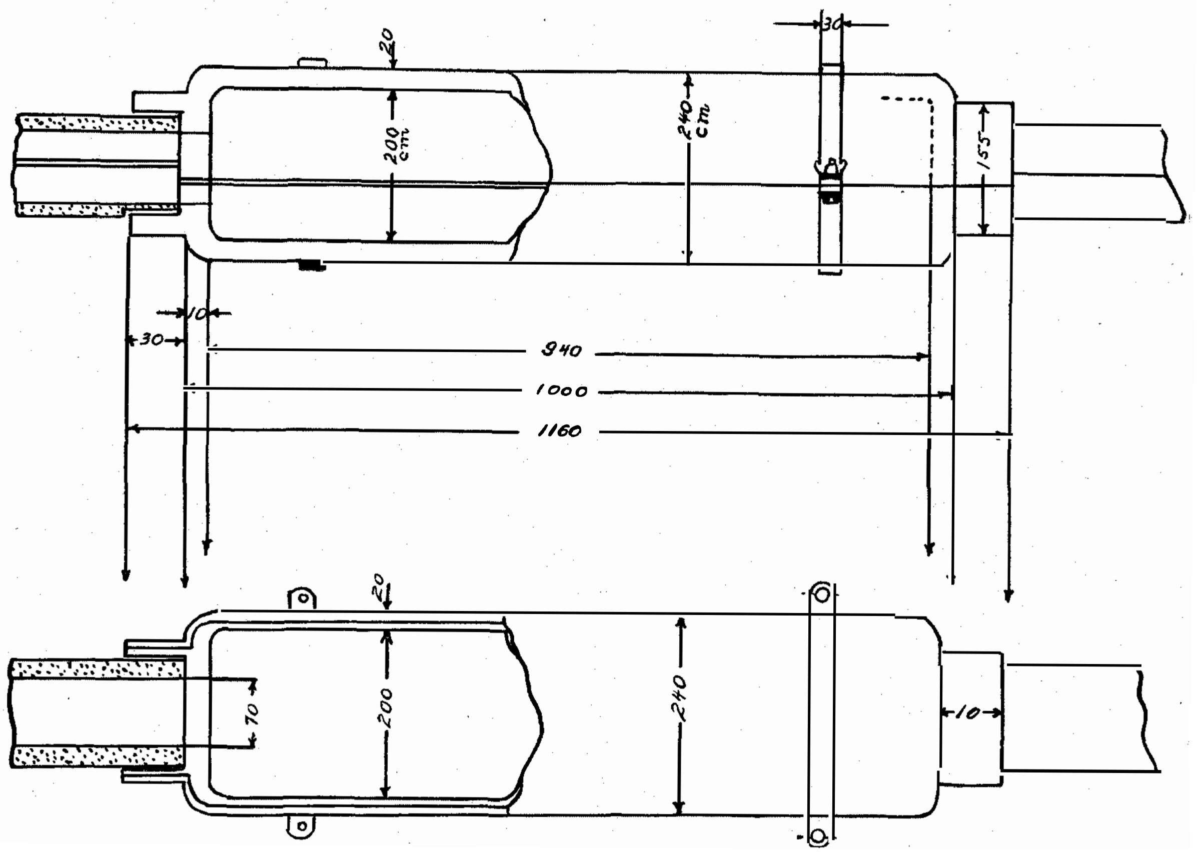


Figure 6

Naturally it is never possible to have the manholes perfectly dry due to the fact that a little water can penetrate through the manhole covers. (Note by translator: the S. I. R. T. I. will be advised to caulk all manhole covers after the work is finished......)

Simultaneously with these works in the Milan district, the construction of vitrified clay duct in various other localities was begun, so that by the middle of February the duct work was completed in Milan, Moro di Locate, Pieve Emanuele, Siziano, Ponte Carate, Porta Pescarina, Casenuove, Castelceriolo, Quargnento, Alessandria città (city), Chieri.

The duct works for Pavia, Alessandria, Cittadella and Genoa are in construction and satisfactory progress is being made.

The pipes for the cables of the urban net-work which in all cases are of the Camp type comprise,

150 meters of 14-way duct
595 meters of 4-way duct
455 meters of 3-way duct
1216 meters of 2-way duct

In the section immediately outside the city of Genoa, a special type of duct described as "Plastic" is proposed since it adapts itself to the conformation of the irregular and tortuous mountainous route. This is composed of a sandstone troughing separated into two parts, of which the lower is buried in concrete which is spread along the bottom to form a foundation for the excavation in the rock. For the sections of the route of great steepness, special anchorages are proposed analogous to those used in reinforced conduit, with the object of assuring the stability of the troughing and of the cable contained in it.

A type of work which is entirely new will be used in the crossing of the torrent Secca, which has a very wide bed and which is not provided with bridges. It is planned here to construct a special duct-line immersed in a buried dike at such a depth as not to be damaged by the torrent.

In the ordinary road, the work of placing was organized so that the men who carry out the excavation should prepare the trench for about 1 kilometer ahead of the placing of the cable. A second gang of workmen places the lower half of the troughing on the bottom of the excavation, lining it up and taking care of the joints. A squad of special workmen follow who, by means of the cable laying cart, lower the cable into the lower half of the troughing which is then closed by fitting the upper half over it. Finally, another gang of laborers carry out the work of refilling and refinishing of the road. The progress of the work may vary from 400 to 1200 meters per day, depending on the various difficulties encountered.

Particular care has been taken for a proper distribution of the material along the route. Concentration yards were established, either in the immediate neighborhood of the cable route and in places served by the railway, or in the localities farthest from the railway. To these stores flowed from the factories the cable drums, the troughing, the ducts, the manhole covers, etc., so that transportation by motor lorries could be reduced to a minimum.

So far these yards have been located in the following places:

First Section: Milan (Central yards), Siziano, Pavia, Barbianello, Pinarolo Po.

Second Section: Voghera, Castelnuovo Scrivia.

The Milan-Turin-Genoa cable, as are all modern toll telephone cables, is formed of quads of four conductors. The quad serves generally to give three simultaneous conversations, one on each of the two metallic circuits which compose it and the third a combined circuit (virtual or phantom). The service which is required from a cable of this type, a cable which includes a much greater utilisation than the constituent conductors, is very different from that of the normal urban telephone cable employed to connect subscribers. The cable, therefore, must be manufactured with different standards and in an entirely special manner.

In order that the two metallic circuits do not interfere with each other and above all that they do not disturb the conversations which take place simultaneously on the phantom circuit and on other real circuits, it is necessary that the four conductors which constitute the quad shall be wherever possible identical along the whole length of the cable, or that the four primary constants, resistance, conductance, capacity and leakance, be equal; when these conditions are obtained, it is said in general terms, that the cable is "balanced."

The idea of giving three conversations on two pairs of conductors is relatively old; its practical application is, however, of recent date since only recently and in consequence of a number of special refinements during the manufacture of the cable has it been possible to eliminate in great part the unbalances of the circuits which compose the quad, thus eliminating the cross-talk between circuits and rendering the three conversations possible and independent.

The most accurate manufacture of the cable does not eliminate completely the capacity unbalances which exist either between the side circuits of a quad or between each side circuit and the phantom circuit formed by them. There first exists unbalances between the capacity of these circuits and those of the circuits of the adjacent quads in the cable. These unbalances of capacity, which are the source of cross-talk, can be reduced and, in many cases, eliminated when making the joints between the various reel lengths of cable during installation.

The modern telephone toll cable is always loaded so that the inductance of the circuits is artificially increased by means of the insertion of Pupin coils. It is observed from the formulæ, which give the secondary constants of the telephone line in cable, that the inductance added has a doubly beneficial effect; not only does it diminish the coefficient of attenuation, permitting the possibility of speaking to proportionately a greater distance, but it also lessens the distortion insomuch that the currents at different frequencies which compose the human voice tend to be transmitted with equal loss, a requisite of the greatest importance for the clarity and intelligibility of reception.

The values of inductance added vary according to the length of service and in general of the type of line and they can be obtained either by employing different coils or by spacing in a different manner. The length of cable comprised between two coil sections is the element constituting the line, in the same manner as the quad is the element of the cable. It is of the greatest importance that the different loading coil sections be all equal so as to avoid reflection losses at the points in which the coils are inserted. It is also necessary that the termination of the cable at the terminal stations and at the intermediate stations be symmetrical and regular so as to avoid reflection losses at these points.

Only after having carried out the topographical survey and the exact measurements of the route was it possible to be certain that the lengths of the loading sections would be exactly equal and that there would not be obstacles (bridges, constructions, etc.) which would cause the displacement of the position of the loading coils with respect to the theoretically calculated points.

The length of the loading section of the Milan-Genoa-Turin cable is about 1.8 kilometers. There are in all 164 loading points distributed as follows:

First Section —No. of Loading points	36
Second Section—No. of Loading points	22
Third Section —No. of Loading points	62
Fourth Section—No. of Loading points	44
Total	164

The cable terminates with a half section at the terminal stations of Milan-Genoa-Turin and at the repeater station at San Giuliano. The same termination is also adopted at Casteggio where the future cable for Rome will leave at the middle point of a loading section.

Since the loading section is a constituent element of the line, it is necessary to carry out the measurements of capacity balance on this length in such a manner as to be sure that all the circuits constituting the cable shall be so far as possible similar to each other and that the mean residual unbalances for every loading section shall be so far as possible low and equal to each other.

Testing and jointing work, which proceed in strict conjunction, were organized in the following manner:

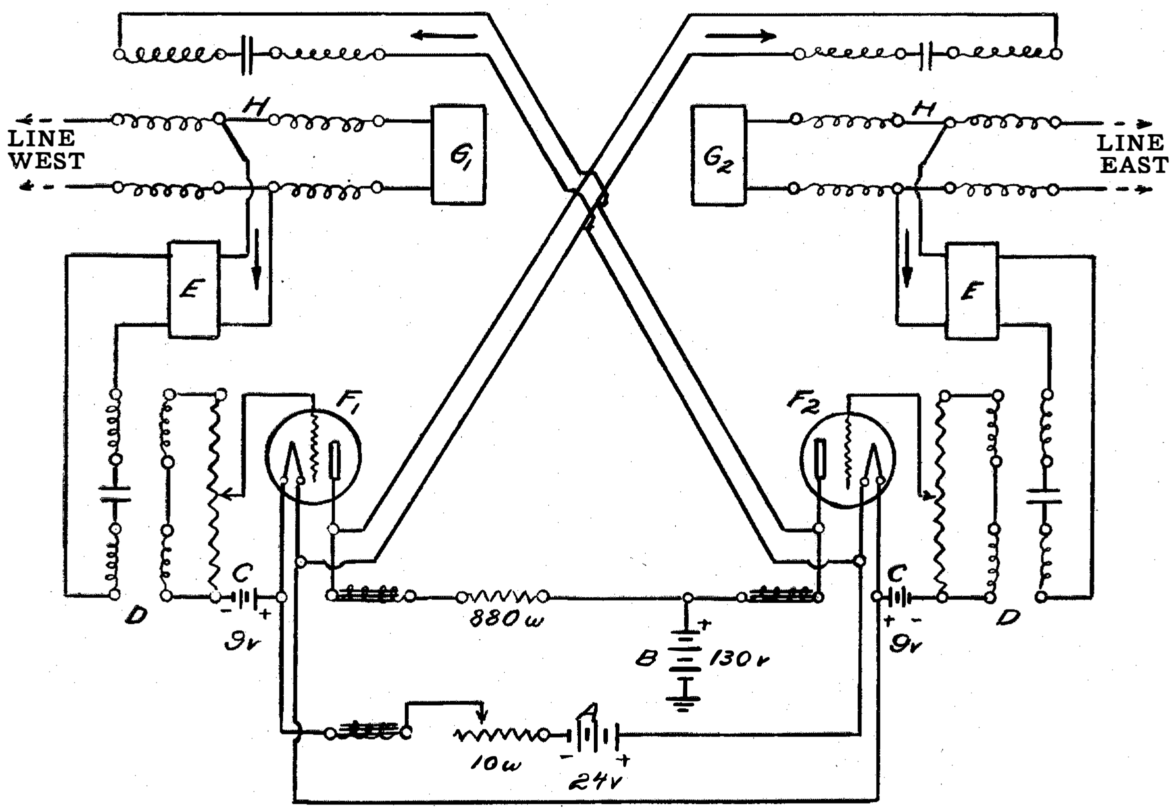
Due to the novelty of the work, it was necessary to train a certain number of testers and jointers, arranging for them to attend special courses both theoretical and practical and making them practice extensively on pieces of cable. Gangs were thus formed, each composed of a tester, a jointer, a Pupin jointer and two helpers, to whom the work in the field was entrusted. In the method of operation, the jointer prepares the ends of the conductors of the two lengths of cable for the tester who tests the unbalances which are recorded on a special form. Based on this work and observing also the results obtained in the adjacent joints in the same loading section, the conductors to be jointed are chosen so as to obtain the least final unbalance. The actual joint is then carried out and the unbalances are finally retested so as to have an exact check of the completed operations.

When a loading section has been finished, the final electrical tests are made. In addition, the whole section is tested for pressure, admitting into the cable compressed carbon dioxide for the purpose of proving if all the joints and lead sleeves are completely sound.

One jointing gang usually works on one loading section. The work, therefore, becomes distributed over a length varying from 7 to 10 kilometers, a stretch which must be continuously covered by the engineers engaged in the work, either for ordinary supervision or for the co-

FIRST SECTION—MILAN-CASTEGGIO

Circuits.	*Diameter Conductors.*	*Type of Circuit.*	*Number of Quads.*
Milan-Turin	1.3	2 wire	9
Milan-Genoa	1.3	2 wire	7
Milan-South Italy	1.3	2 wire	3
	0.9	4 wire	16
Telegraphs	0.9	......	4
Reserves	0.9	......	4
	Total		43



D—INPUT TRANSFORMER E—FILTER
F_1, F_2—REPEATERS G_1, G_2—ARTIFICIAL LINES
H—OUTPUT TRANSFORMER

Figure 7

ordination of the results obtained in the single tests. There are on the works an engineer in charge of the testers, one in charge of the jointers and a third with general directive functions, and they have at their disposal two motor cars.

The composition of the cables, the number of circuits and their distribution in the four sections of the cable Milan-Genoa-Turin is shown by the following table:

SECOND SECTION—CASTEGGIO-S. GIULIANO

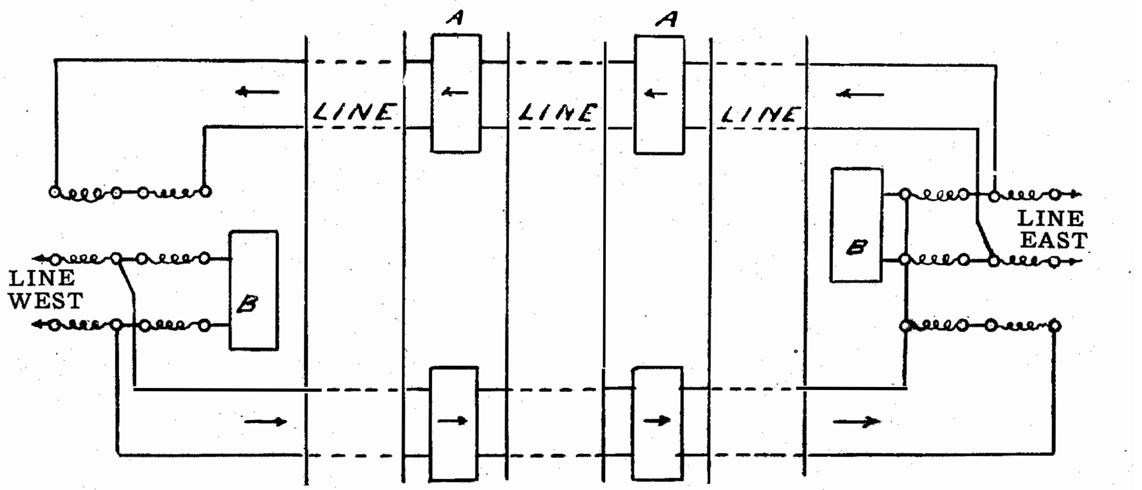
Milan-Turin	1.3	2 wire	9
Milan-Genoa	1.3	2 wire	7
Turin-South Italy	1.3	2 wire	2
	0.9	4 wire	8
Genoa-South Italy	1.3	2 wire	3
	0.9	4 wire	10
Telegraphs	0.9	......	5
Reserves	0.9	......	7
	Total		51

THIRD SECTION—S. GIULIANO-TURIN

Milan-Turin	1.3	2 wire	9
Turin-South Italy	1.3	2 wire	2
	0.9	4 wire	8
Turin-Alessandria	0.9	2 wire	2
Turin-Genoa	1.3	2 wire	4
	0.9	4 wire	2
Telegraphs	0.9	......	4
Reserves	0.9	......	5
	Total		36

directions). Every quad is equipped with three of such groups, two for the physical circuits and one for the phantom circuit.

Figure 8 shows on the other hand a skeleton of a 4-wire circuit. In the repeater stations, there are amplifiers with two valves in series amplifying in one direction only as shown by the arrows in the figure. Two quads serve for three of such circuits, two physical and a third phantom, and in these are installed three amplifying groups. The 4-wire circuit serves for the long communications on account of the much greater stability which it has in comparison with the 2-wire circuit.



A—STATION REPEATER B—ARTIFICIAL LINE

Figure 8

FOURTH SECTION—S. GIULIANO-GENOA

Genoa-Milan	0.9	2 wire	7
Genoa-Turin	0.9	2 wire	4
Genoa-Alessandria	0.9	2 wire	2
Genoa-South Italy	0.9	2 wire	3
	0.9	4 wire	10
Turin-Genoa	0.9	4 wire	2
Telegraphs	0.9	......	2
Reserves	0.9	......	5
	Total		35

From the foregoing tables, it will be seen that the telephone circuits of the cable are divided into two groups, 2-wire circuits and 4-wire circuits. It will also be seen that the 4-wire circuits serve only for communications with very distant centers, while the communications between Milan-Genoa-Turin are served by the 2-wire circuits.

Figure 7 shows schematically the principal amplifying circuit of a 2-wire line employing an amplifier of the 22 type (so called because it is furnished with two valves, and amplifies in two directions).

From the diagram, it will appear that every 22 type repeater employs two artificial lines to balance a line west and a line east, while in the 4-wire circuit the artificial lines are reduced to two only at the two terminals. Since the artificial lines never reproduce the characteristics of the lines in an exact manner for all the frequencies used, it follows that the smaller the number employed, the greater will be the gain at which the amplifiers can be worked; therefore, for a given attenuation, the greater the distance over which commercial conversations can be established.

Because the type of service for which the 4-wire circuits are designed calls for different line constants than those required for the 2-wire circuits, it is necessary to use different loading coils; to be exact, the physical circuits of a 2-wire line are loaded with coils of 253 millihenries of inductance and the phantom circuits with coils of 156 millihenries; similarly the physical circuits of the 4-wire line car loaded with coils of 177 millihenries and the phantom circuits with coils of 107 millihenries.

These inductance coils are mounted in columns and enclosed in iron cases, each of which contains,

32 coils for physical circuits 2-wire
16 coils for phantom circuits............2-wire
8 coils for physical circuits 4-wire
4 coils for phantom circuits............4-wire

These coils serve for loading 20 quads; partly for 2-wire circuits (16), partly 4-wire circuits (4).

Initially only 20 quads are being loaded, the manholes destined to contain the loading coal cases (Figure 9) being constructed so as to permit the placing of a second pot when it shall be necessary to utilize all the circuits of the cable.

The building for the repeater station situated at S. Giuliano, the construction of which was begun on November 15, 1922, is to contain the equipment of the repeater sets, the accumulator batteries for the service of the station, the electro-generating machinery for the charging of the batteries, the necessary circuits for testing, measuring and all the other auxiliary services. All of the 4-wire repeaters will not be installed at first because these are not necessary for the communications between Milan-Genoa-Turin; they will be installed ultimately when the cable shall be extended to the south of Casteggio towards Bologna, Florence, Rome and Naples.

The San Giuliano Station, as also the three terminal stations, are constructed, however, in

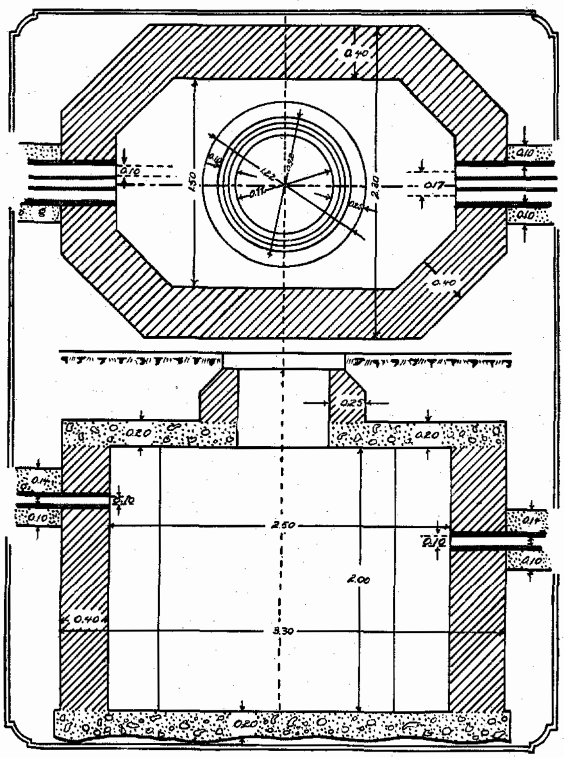


Figure 9

such a manner that, if the need arises, the 4-wire circuits can be utilized as 2-wire circuits in case the number designed for 2-wire service is found to be insufficient for the needs.

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