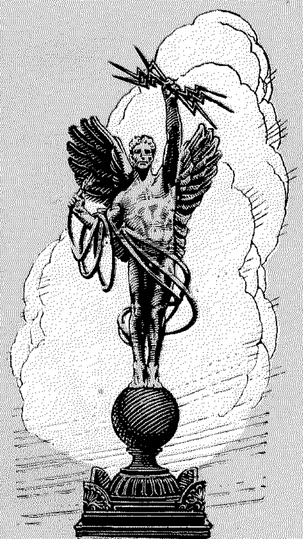
ELECTRICAL COMMUNICATION



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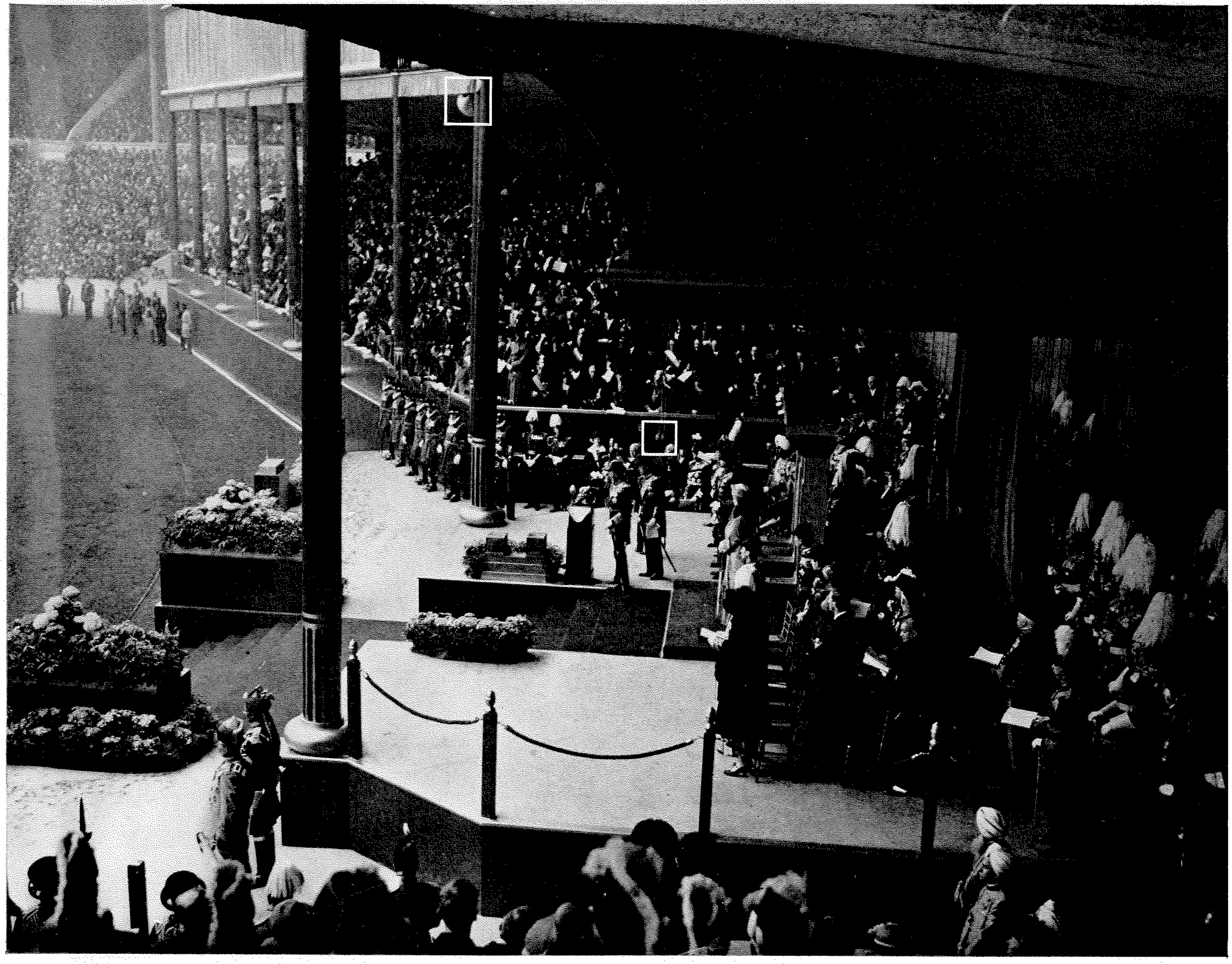

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The King Opening the Empire Exposition at Wembley

[Upper White Square Encloses Projector
Lower White Square Encloses Microphones]

Demonstrations of the Public Address System in Europe

By A. F. RICKARD
Engineering Department, Western Electric Company, Ltd.

Developments in Great Britain

FOLLOWING development work in the United States on the part of the Western Electric Company, Inc., the Public Address System was introduced in Great Britain in 1922. Since then, as the extent and variety of applications of the System have been disclosed, the character of the demonstrations has increased in variety. Notwithstanding many difficult conditions of operation over a wide range of work, excellent results always have been obtained. The System has been applied indoors and out of doors; it has been used for the amplification of important speeches at meetings and at public dinners; the reproduction of speeches or music in buildings remote from the speaker; reinforcing orchestras and bands; announcing purposes; the distribution of gramophone or orchestral music over large areas; and the amplification of wireless reception.

The first occasion on which the Public Address System was employed in public in England was for the official opening of the Marine and Yachting Exhibition at the Agricultural Hall, Islington, London, on November 14, 1922. (Figure 1). H.R.H. The Duke of York, speaking from his private apartments at Buckingham Palace, declared the Exhibition open. His voice was reproduced by eight projectors suspended in a group from the roof of the Agricultural Hall. The Public Address transmitter was installed in the Duke's apartments and connected to a 2-stage amplifier. The output of this amplifier was connected to an ordinary telephone junction-line leading to the Agricultural Hall, where it was brought in direct to the Public Address System amplifier. A second junction-line, between the Agricultural Hall and Buckingham Palace, was provided for direct telephonic communication.

In addition to the arrangements for the transmission of the Duke's speech, provision was made for the amplification of the speeches from the lounge in the centre of the Hall, where the speakers took up positions beneath the projectors. From the lounge, Major Hunloke, the King's Yachtsman, introduced the Duke to the audience. The line from Buckingham Palace was then switched in and the Duke from his apartments at the Palace opened the Exhibition with a speech, every word of which was loudly and distinctly heard in every part of the Agricultural Hall. Throughout the Exhibition the system was in constant use for speeches, announcements, music and amplification of broadcast reception from the London Broadcasting Station.

When His Majesty the King visited the Marine and Yachting Exhibition, he asked for a special demonstration of the Public Address System for the reproduction of speech from Buckingham Palace. His Majesty showed considerable interest in the installation.

The first use of the No. 1 System in England was in December, 1922, when a private demonstration was given on the estate of Colonel Grant Morden, M.P., at Heatherden Hall, Uxbridge. For this demonstration two large wooden projectors were mounted on the upper balcony of the Hall in such a way as to project the speech and music into the gardens and grounds beyond, a distance of three to four hundred yards. The transmitter in the pedestal mounting was placed on the terrace immediately beneath the two projectors and was used by various speakers with different types of voices to demonstrate how the whole of the ground covered by the projectors could be filled with the amplified voice of each speaker.

When a speaker with a powerful Scottish accent arose and "barked" into the instrument, fears were expressed for the safety of the microphone, but the whole equipment, although of Anglo-Saxon construction, responded nobly, yielding perfect clearness of speech. A second transmitter, placed inside the main hall of the house, reproduced gramophone music over the same area with like efficiency.

During the early part of 1923, the No. 2 System was used for a number of indoor installations. The first of these was the Annual Dinner

Figure 1—Yachting Exhibition, Agricultural Hall

of the Institution of Electrical Engineers, held in the Grand Hall of the Hotel Cecil on February 5, 1923. Two groups of projectors were erected, one on each side of the Dining Room, so that the speeches could be made from either side. The projectors were mounted on semi-circular structures of iron, screwed to the window-sills and braced to the walls. The transmitters were placed on the tables in positions corresponding to the places of the speakers, the transmitter cables running along the underside of the tables to the amplifying apparatus. This was the first indoor demonstration of its type carried out in England with the Public Address System, and the importance of the acoustic problem presented by comparatively small halls was thrust home forcibly to those responsible for the demonstration.

Mr. Frank Gill, European Chief Engineer of the International Standard Electric Corporation, at that time President of the Institution of Electrical Engineers, was in the chair. Other speakers were Sir William Joynson-Hicks, Bart. M. P., Mr. Neville Chamberlain (then Postmaster General), Mr. J. S. Highfield (Past President) and Sir Arthur Colefax, K. B. E., K.C.

The next application of the Public Address System was at the Annual Dinner and Smoking Concert of the London and South Western Railway at the Coliseum, Southampton. Here its use prevented the occurrence of an unfortunate situation. On previous occasions, the massed railway employees of all grades, unable to hear the speeches, generally discussed their own private affairs in the background or burst forth into song, in competition with the official speakers. The System amplified the speeches and concert items with complete success, so that for the first time in the history of these concerts the whole audience remained quiet throughout the speeches and concert items with no attempt at "opposition." Those at the back of the hall stated that they heard everything perfectly and without effort.

The installation was simple, two groups of projectors being necessary, each group suspended from a girder in the roof. The main group of four projectors at one end of the hall was used for the principal speakers at the head of the chief table, and also for the amplification of concert items. The second group consisted of two projectors and was erected in the far corner of the hall to give out the response of a workman to a special toast. As the transmitters were placed opposite the speakers, it was unnecessary for any of them to move from his place to make a speech. A transmitter in a special housing was mounted on the stage and arranged so that it could be moved to the best position for any particular item.

On April 6, 1923, a demonstration was carried out on Victoria Railway Station, the terminus on the London-Brighton and South Coast Section of the Southern Railway. Projectors erected on one of the large columns distributed sound over the area where crowds congregated while waiting for trains. A large number of announcements, which applied to the traffic conditions at the time, were made over the system to demonstrate to officials of the Railway and of the South Eastern and Chatham Section the usefulness of the System. Notwithstanding the noises incidental to a large railway terminus, the announcements could be heard without difficulty.

On April 11, 1923, at Southampton, the utility of the System in directing ships into the docks and issuing instructions was demonstrated to a number of important railway and shipping managers. For this purpose, an extra large wooden projector, consisting of four sections, was constructed. The position chosen for the demonstration was at Berth 37, the most forward in the docks, at which point the River divides. The remaining berths are located on both sides of the two branches. About thirty managers and representatives of various railway and shipping companies arrived for the demonstration and boarded a tug at Berth 37, steaming slowly down towards the sea. Speech was commenced as soon as the tug left the Berth, and the proper direction and vertical angle of the projector was maintained by the man at the crane so as to follow the tug in its course. Those on the tug found that they could still hear the speech when about one and a half miles from Berth 37 and for a considerable time the tug cruised about at distances between one mile and two miles. On the return trip, it was stated that the projected voice could be understood up to one and a half miles.

The Summer of 1923 opened a new field for the activities of the Public Address System—the control and announcements required at Athletic

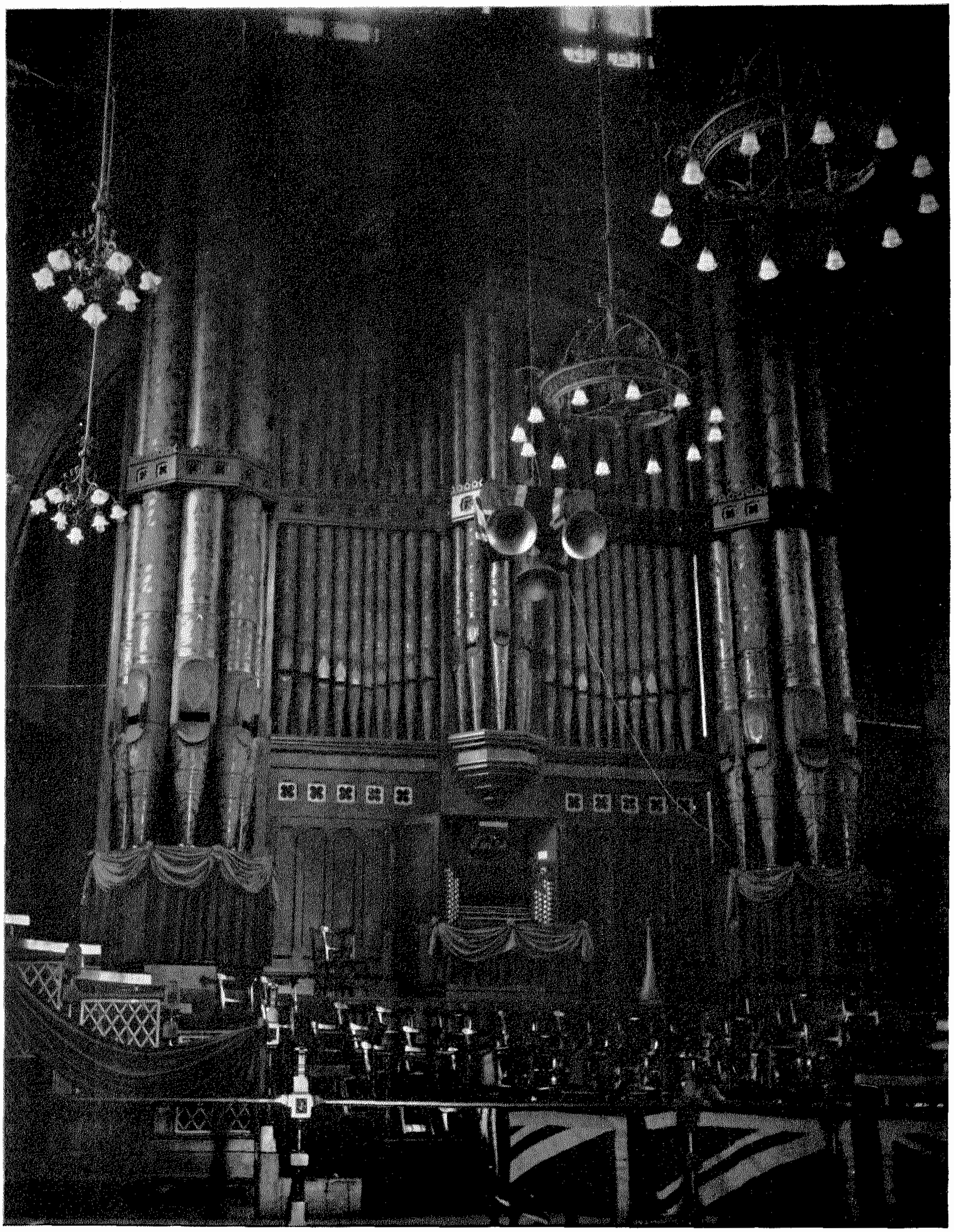

Figure 3—Public Address System—Palladium, Plymouth

Sports Meetings. Although a portable equipment erected in a lorry was ready for demonstration work, it was not always possible to use it for Sports Meetings, as the Sports Ground Authorities would not permit the lorry to be driven over the track into the arena. Generally it was found easier to dismantle the apparatus and install it in a small tent in the middle of the arena. Normally a group of nine projectors was used, erected on a tripod at the center of the arena, so as to cover a complete circle, thus projecting the voice to every point round the track, where the spectators were assembled. These arrangements were used for the first time at the Annual Sports Meeting of Joseph Lyons & Co., at Sudbury, on May 19th, and were completely successful. As several events were in progress simultaneously throughout the afternoon, it would have been impossible without the Public Address System to announce results to the crowd, which numbered about ten thousand people. At this and all other Sports Meetings where the System was installed it was found extremely useful for a multiplicity of purposes—calling out competitors to their marks, stating previous records, stating changes in programme, calling absentees and officials, arranging personal meetings, finding the parents of lost children and finding the owners of lost property.

Similar successful demonstrations were carried out at many other Sports Meetings, including The Polytechnic Harriers' Gathering at Stamford Bridge on June 16th; Navy, Army and Air Force Institute Sports at Mitcham on July 7th; Motor Cycle Gymkhana at Birmingham on July 21st; Metropolitan Police Sports at Eltham on July 26th; and the "News of the World" Sports at Stamford Bridge on August 6, 1923.

The "News of the World" Sports, which was attended by over 32,000, was by far the largest meeting. At the conclusion, Lord Cadogan, President of the Olympia Games Association, made a speech over the System, much to the delight of the huge crowd.

In a demonstration at Brighton during Carnival Week, 1923, the No. 1 System was used for the distribution of band music along the promenades by the sea front and in the Old Stein Gardens. (Figure 2). By placing projectors on the roofs of hotels and buildings to direct the music along the promenades, two miles of sea front were provided with music. In the gardens, the projectors were located in such a way as to cover not only the gardens themselves, but also the main streets leading to them. The band was on Madeira Terrace and a control room was built in the sheltered promenade immediately

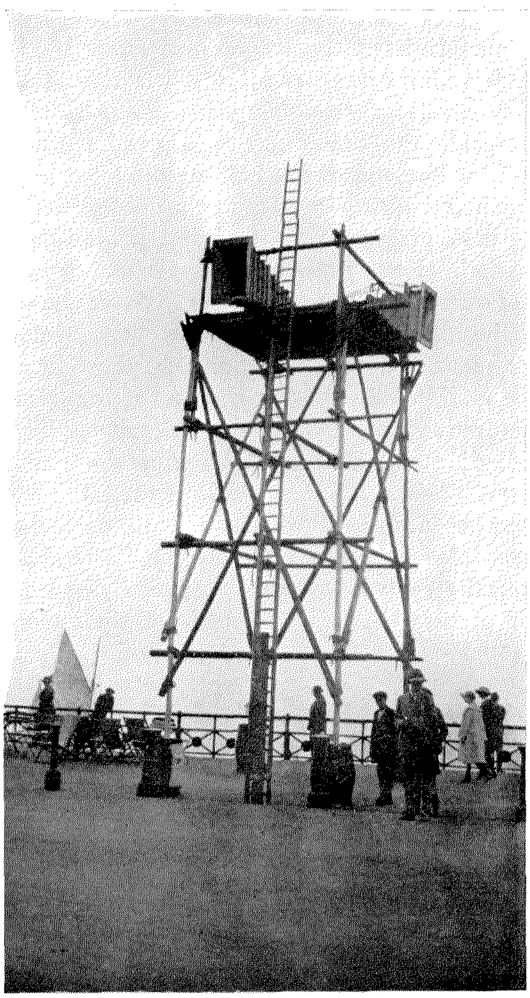

Figure 2—Scaffolding at Brighton Carnival Carrying Projectors

beneath. Over five miles of twin lead covered cable were laid for connection to the various projectors.

In September, 1923, the smallest Public Address System, known as No. 3, came into general use for small indoor demonstrations. Important demonstrations of this System took place on September 17th and 19th at Port Sunlight; on October 11th at the Hotel Great Central; while from October 12th to October 20th the System was in use daily at the Scientific Exhibition at Surbiton.

The first use of the Public Address System in England for a political meeting was on September 23, 1923, in the Palladium, at Plymouth. (Figure 3). The occasion was a large political meeting of the Conservative Party, at which the Prime Minister, the Rt. Hon. Stanley Baldwin, made an important speech. The Public Address lorry used for this demonstration was parked alongside the building. A large platform was built at one end of the hall, at the front edge of which and approximately at the center, the reading desk pedestal with transmitter housing, was located. Four projectors were slung from the roof over the transmitter so as to cover the whole of the audience. The speeches were reinforced in the Palladium itself, and were reproduced in the Guildhall, a building situated about eight hundred yards away. The attendance at the Palladium was nearly 7000, and in the Guildhall about 3500. The system rendered all the speeches audible throughout both these buildings. A few weeks later, at the General Election, the System was used extensively by a number of candidates in prosecuting their election campaigns.

In March, 1924, a series of experiments and trials was carried out in Westminster Abbey with the Public Address System with a view to making the sermons and lessons audible in every part of the Abbey. The acoustic problem and the question of location of projectors involved many difficulties. The Abbey, in common with many churches and cathedrals in Great Britain, possesses acoustic properties which cause reverberation and echo, and it was only after considerable experimenting that results with the Public Address System could be freed from objectionable reverberation which would ruin the tone and intelligibility of the projected speech. A further difficulty arose in connection with the projectors, as the Abbey Authorities stipulated that the projectors should not be plainly visible to the congregation and should not interfere with or hide any part of the fabric. However, by using the folded type of wooden horn these objections were overcome. The choir and the North and South transepts were dealt with in this way, but for the Nave it was found essential to use a straight wooden horn of medium size placed in the screen and turned on its side. The System was officially used on Easter Sunday, April 20, 1924, for the morning, afternoon and evening services, for the reading of the lessons from the lectern and for the sermons from the pulpit. Since that time, it has been installed and operated on several occasions for the Sunday services, one of these being during the visit of the American Advertising Convention in July, when two thousand delegates and their friends attended the services at the Abbey.

The most important operations with the Public Address System were at the official opening in April, 1924, of the Wembley Exhibition by His Majesty the King. An enormous dais of purple and gold was erected at the east-end of the Stadium, in the center of which and immediately over the thrones of Their Majesties the King and Queen, was a canopy of scarlet and gold surmounted by a gilded crown. Five large wooden projectors were placed inside the canopy and were arranged to cover the great terraces of the Stadium where more than 100,000 people were assembled to watch the opening ceremony and to hear the King speak. Owing to the immense significance of the occasion, the amplifiers were duplicated and the control-room was established beneath the Royal platform. Two transmitters were suspended from the canopy, over the throne, one for the King, the other for the Prince of Wales. The housings of these transmitters, the light chains which supported them, and the cords leading from the transmitters, were gilded to harmonize with the surroundings.

The first speech was by the Prince of Wales, President of the British Empire Exhibition, to welcome the King (Figure 4) and to describe the objects of the Exhibition. From the beginning of the Prince's speech, the crowd quieted. All could then hear every word. At its conclusion, His Majesty the King replied, and his more powerful voice was heard with even greater effect. After the King had spoken, the Bishop of London read a prayer, and then led the crowd in the repetition of the Lord's Prayer. This perhaps was the most impressive part of the ceremony—a hundred thousand people, led by one, whispering the Lord's Prayer.

On the same day, the Music Distributing System in the Amusements Park of the Exhibition came into operation. Actually its initial use was for broadcasting the King's speech which was received on a radio receiving-set and then distributed through the System. This System fed eight groups of projectors, each group consisting of four or more projectors, the groups being located in various parts of the Amusements Park. It was in use from 11 a. m. until 8 p. m. for the distribution of gramophone music.

A special control room was built for the Music Distributing System, containing a studio, apparatus room, battery-room and battery charging equipment. The cables feeding the various groups of projectors, together with telephone-cable for observation purposes were buried in the ground and consisted of armoured lead-covered cable. Distributing boxes at various points facilitated routine testing and telephonic communication with the control operator.

The Public Address System was next in use at the Stadium during the International Cowboy contests, known everywhere as the "Rodeo," from June 14th to July 4, 1924. It operated throughout the contests as an announcing medium, and was of enormous benefit to the organizers and to the public generally.

A scaffold thirty feet high and fifteen feet square was erected at one end of the Stadium, and the projectors were fixed in position at the top. A platform seven feet from the ground was provided for the announcer, who was thus visible to the public, and to the operators in the control-room established underneath the platform. Although considerable precautions were taken to safeguard the apparatus in the control-room, a wild steer forced his way in on one occasion, much to the consternation of the two engineers operating the equipment, and it was only with great difficulty that he could be persuaded to relinquish his desire for information and to leave the control-room and the engineers in peace.

A series of important demonstrations was carried out during the summer of 1924 in the Royal Albert Hall, London, using the No. 2 System. The projector-system was slung from the roof and guyed into the desired position. It consisted of two rows of projectors, the lower row of five, of the No. 6-A type, serving the stalls, the Amphitheater and lower boxes, the upper row of four folded type box horns serving the upper boxes, upper circle and the gallery. The transmitter was housed in the pedestal stand, and the amplifier system was fitted under the stage. The system was employed at the Albert Hall on five occasions: on May 14th, by the London University during the presentation of degrees to graduates of that University; on May 16th by the Society for Propagation of the Gospel; on May 18th by the International Bible Students' Association on the occasion of the visit of Judge Rutherford from America; on June 30th by the Salvation Army; and on July 16th by the Anglo Catholic Congress. Although Albert Hall possesses notoriously bad acoustic properties, the equipment gave most satisfactory results.

A large number of demonstrations was carried out also with the No. 3 System. The first was the luncheon given at the reception of the King and Queen of Roumania by the Lord Mayor of London on May 13, 1924. Several members of the Royal Family were present, and the speakers were the Lord Mayor and the King of Roumania. A transmitter was placed on the luncheon table opposite each of the speakers, and hidden in clusters of flowers. The voice projectors were secured to a large chandelier immediately above the speakers. The Public Address System came well up to its reputation and enabled the speeches to be heard clearly and without effort by every person present. A very similar luncheon was held in the Guildhall on May 27th for the reception of the King and Queen of Italy, when the System was used again and was equally effective. The installation at the Guildhall was used also on May 23rd for the ceremony of presenting the freedom of the city of London to H.R.H. Prince George, as well as on June 5th for the dinner of the Metallurgy Congress, and on the occasion of the dinner held in honor of the American delegates of the Bar Association.

Many other demonstrations of the No. 3 System were given, among which may be mentioned that at the historical Westminster Hall on July 21, 1924, on the occasion of the official reception of the members of the American and Canadian Bar Association, when the chief speakers were Lord Haldane, who was then the Lord Chancellor, and Judge Hughes of America. Another occasion of importance when this System proved its great usefulness was at the Victoria Hotel on July 21, 1924, for the "Pilgrims" Dinner when

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Figure 4—Prince of Wales Inviting the King to Open the Exposition

H.R.H. The Duke of Connaught was the chief speaker.

Developments on the Continent of Europe

Corresponding progress in the application of the Public Address System has been made on the continent of Europe. During the Olympic Games of 1923 at Paris, the No. 1 System was used. In September, 1924, at the meetings of the League of Nations a noteworthy contribution was made in extending and reinforcing the utterances of the various speakers. At the gathering upon the Plateau Trilbardon, held in memory of Marechal Gallieni, a like service was rendered.

Belgium and Holland also have made considerable progress (Figure 5) in the application of the Public Address System, especially on the occasion of religious and other festivals. Recently it was used at the inauguration of a memorial service at Antwerp, as well as at the Eucharistic Congress at the Amsterdam Stadium.

New applications for the use of the No. 1, No. 2 and No. 3 Systems on the continent of Europe are being disclosed almost daily. Governments, public bodies and large establishments find advantages in possessing and operating the equipment themselves.

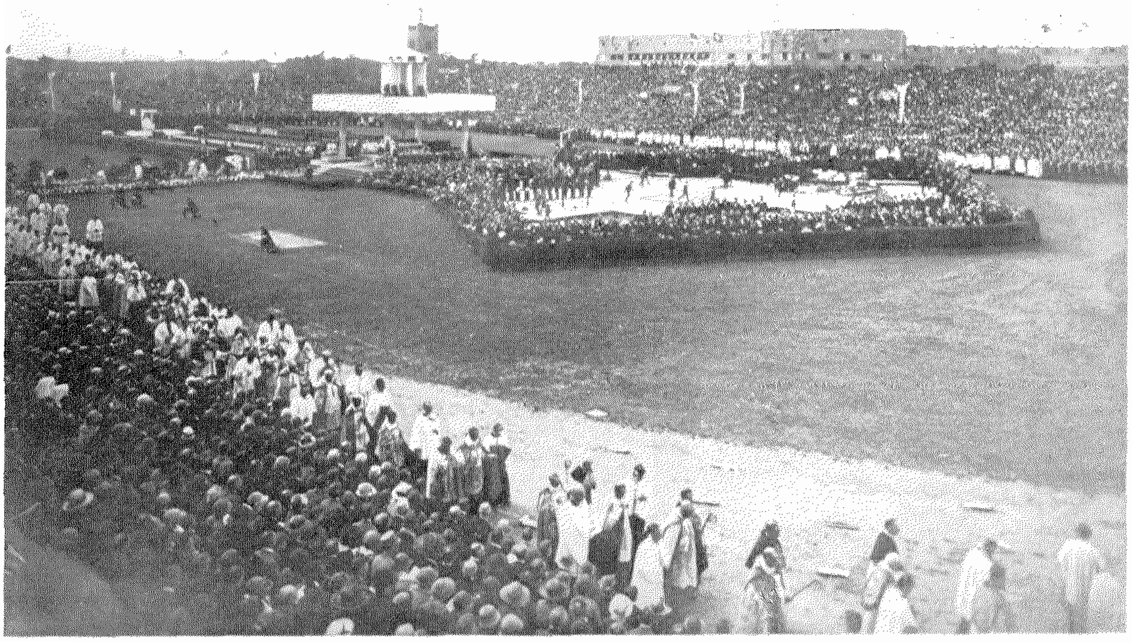
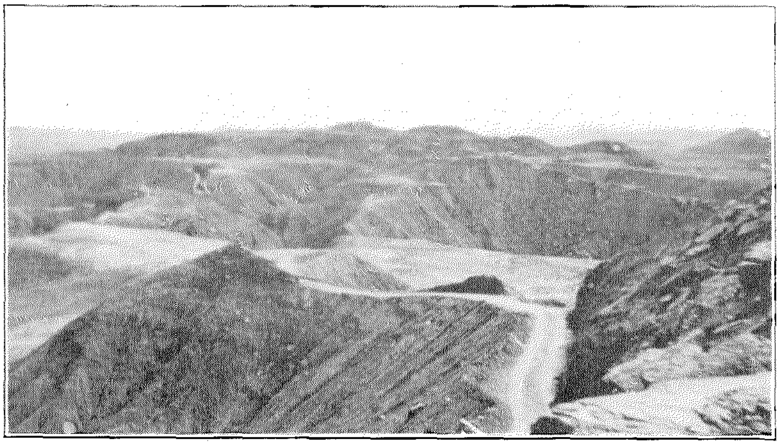


Figure 5—Inauguration of Eucharistic Congress, Amsterdam Stadium

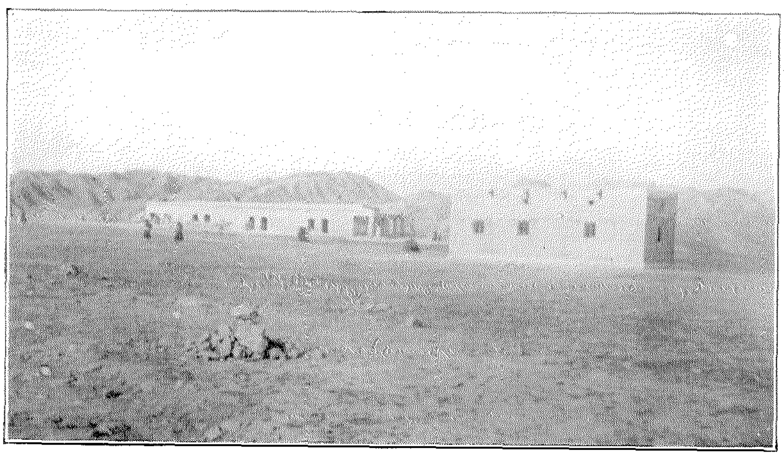
Future Uses

The Public Address System has been available only for a comparatively short time. Predictions as to its ultimate possibilities seem futile, but successful application to date, under a wide variety of conditions, gives assurance of an ever increasing field of usefulness.



The Intervening Country

Unskilled Labour Employed



One of the Stations

Point-to-Point Radio Telephone Installation in Southern Persia

By F. TOMLINSON

Engineering Dept. Western Electric Co., Ltd.

RADIO telephone communication was established recently in the case of some detached workings located in the mountains of Southern Persia, about sixty miles from head-quarters on the coast of the Persian Gulf. The intervening country is extremely broken, and during the rainy season the "road" is occasionally impassible for weeks at a time. The erection of a land telegraph or telephone line would have been a most difficult and costly undertaking, and owing to the damage caused by rain, insects, and looting by wandering tribes, the maintenance of such a line would have been almost impossible. Choice between radio-telegraphy and radio-telephony was decided in favour of telephony, chiefly because of the absence of skilled telegraph operators, and also because of the desirability of securing means for personal communication, if necessary, between any two principals of the Administration at the respective stations. Lack of skilled operators further necessitated the introduction of an automatic "calling" system and the very simplest method of operating the equipment.

The purpose of this paper is to describe the equipment, operation and installation of the system. While the description covers a specific installation, it is obvious that similar applications of point-to-point radio are possible wherever communication is essential between two or more points over territory so undeveloped or of such a nature as to render impracticable communication by postal service, line telegraph or line telephone.

In this system, the apparatus may be considered under the three headings—

(*a*) The Radio Transmitter and Power Apparatus.

(*b*) The Radio Receiver.

(*c*) The Automatic Signalling Equipment.

(*a*) *The Radio Transmitter*, Figure 1, converts the D.C. power supplied by the Motor Generator Set, Figure 2, into alternating current at high frequency, it provides the means of modulating this high frequency alternating current in accordance with the speech-currents derived from the telephone-transmitter of the desk-stand, and it applies the modulated "carrier" to the antenna system. The Motor Generator Set supplies the D.C. power necessary for the filament and plate-circuits of the valves (vacuum tubes). It consists of one high-voltage and one low-voltage D.C. generator, both direct-coupled to a suitable driving motor. The power panel, Figures 3 and 4, contains all the necessary switches, fuses, meters and circuit breakers for the control of the motor and generators.

(*b*) *The Radio Receiving Set*, Figure 5, transforms the received high-frequency energy into an audio-frequency current and amplifies this energy to a proper level for telephone reception.

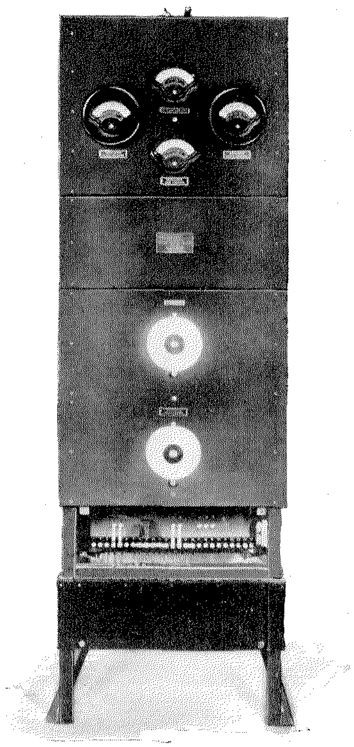
(*c*) *The Automatic Signalling Equipment* is divided into two parts:—

(1) The Receiver, which is contained in the Signalling Unit, Figures 6, 7 and 8.

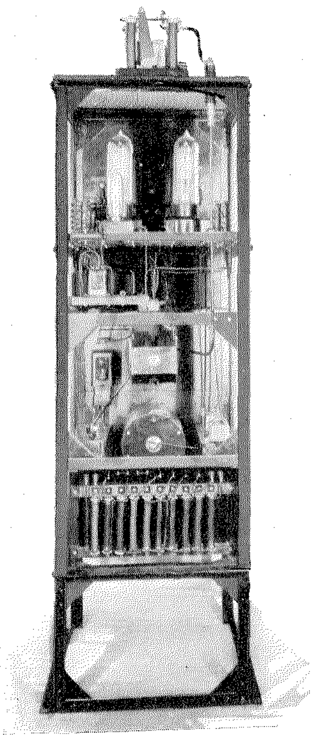
(2) The Transmitter, consisting of the Interrupter Unit, Figure 9, the Selective Signalling System, Figure 10, and the Selector Key, Figure 11.

The current from the microphone passes through an induction coil in the subscribers-set, to the input-transformer in the Radio Transmitter. The voice-frequency current-changes are then amplified to a sufficient power-level to produce such variations of the grid-potential of the two modulator valves in parallel as will ensure that these valves operate only over the straight and nondistorting portions of their characteristic curves. Precautions are taken in adjusting the steady grid-potential of these valves so that the maximum power can be handled without distortion.

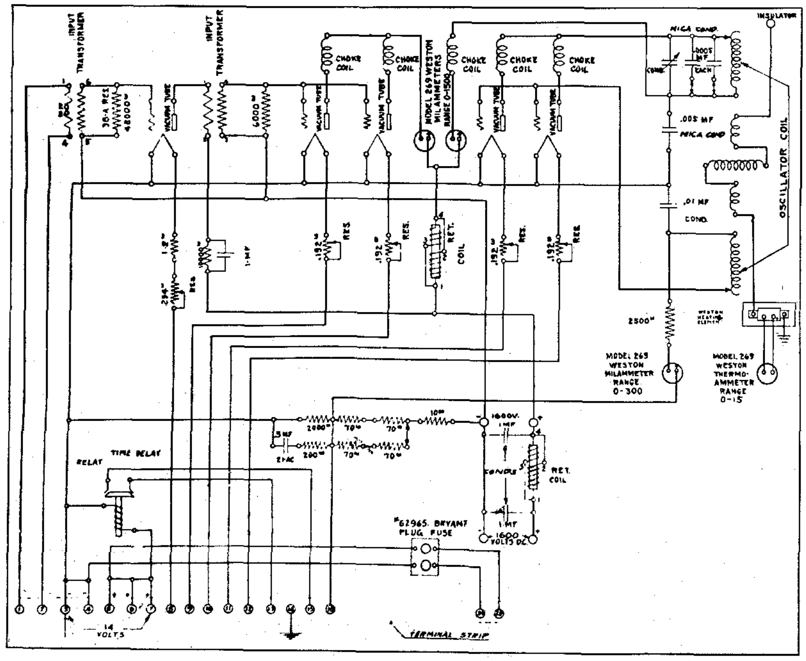
The direct-current supplied to the valves must be converted into alternating current of high frequency before power can be radiated from the



Radio Transmitter—
Front



Radio Transmitter—
Rear



Radio Transmitter—Circuit Diagram
Figure 1

antenna system. This operation is performed by the two oscillator valves in parallel. By suitably arranging the values of the capacity and inductance in the grid and plate circuits of these valves, and the coupling between the two circuits, an oscillatory current is produced and is applied through a "vario-coupler" to the antenna circuit. This oscillatory current will remain steady in amplitude unless interrupted or varied by some external means. The function of the modulator valves is to vary the steady amplitude of the oscillatory current or "carrier" in accordance with the voice-frequency current-changes received from the telephone transmitter. For this purpose a highly inductive "choke" is connected in the common high-tension supply to the modulator and oscillator valve-plates so that the total current through the "choke" cannot vary at and above voice frequencies. The voltage variations applied to the grids of the modulator valves cause corresponding variations in their plate currents. As, however, the total current through the "choke" cannot vary, these changes are transferred to the oscillator plate circuit and thence to the antenna system.

The current-changes produced in the telephone transmitter by the voice are thus superimposed upon the high-frequency "carrier" and they are in this way radiated from the antenna-circuit.

Tuning of the antenna circuit is effected by varying the inductance of the "vario-coupler," the plate-circuit being tuned by "tappings" on the coupling coil. A filter-circuit included in the high tension supply, prevents any "ripple" in the "feed" to the plate circuits from appearing in the radiated wave.

For simplex working, a push-button which must be depressed during speech, is included in the desk-stand. It completes the battery-circuit to an aerial change-over relay, which has two functions:

(1) It connects the antenna to the radio-transmitter and disconnects the Receiving Set.

(2) It short-circuits a resistance of 2000 ohms.

When this resistance is not short-circuited a high negative potential is applied to the grids of the oscillator valves. This potential is obtained by causing the combined plate-currents from all the valves to flow through the 2000 ohm resistance to the negative pole of the generator. The increased negative grid-potential in the non-operated or "Receiver" position, prevents the oscillator-valves from oscillating. On releasing the push-button for reception, the aerial relay falls to the non-operated position; this connects the antenna to the radio-receiver and also stops the oscillator-valves from oscillating, as described above. When the transmitted speech-waves arrive at the receiving antenna the small radio-frequency oscillations are first amplified by two amplifier valves with transformer-coupling. The amplified high-frequency currents are then applied to a detector-valve employing grid-leak rectification whereby the radio-frequency current is converted into direct current which varies at audio frequency, thus reproducing the original speech-variations. To raise the energy level to that necessary for telephone reception, this current is then amplified by one low-frequency transformer-coupled valve.

The system employed for automatic "calling" is to apply to the radio-transmitter an alternating

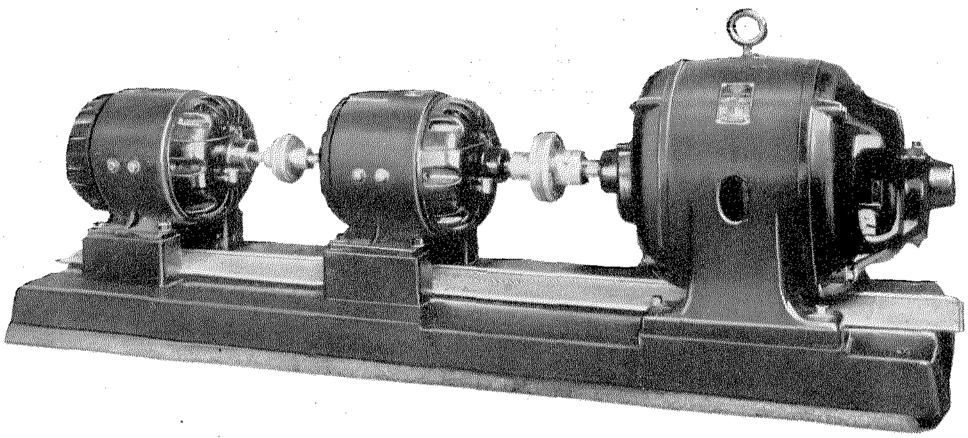
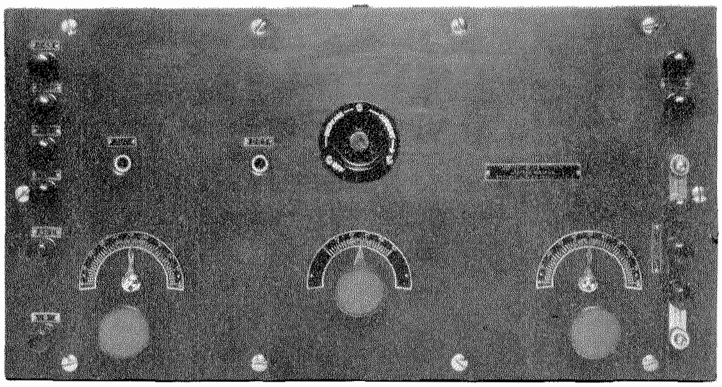
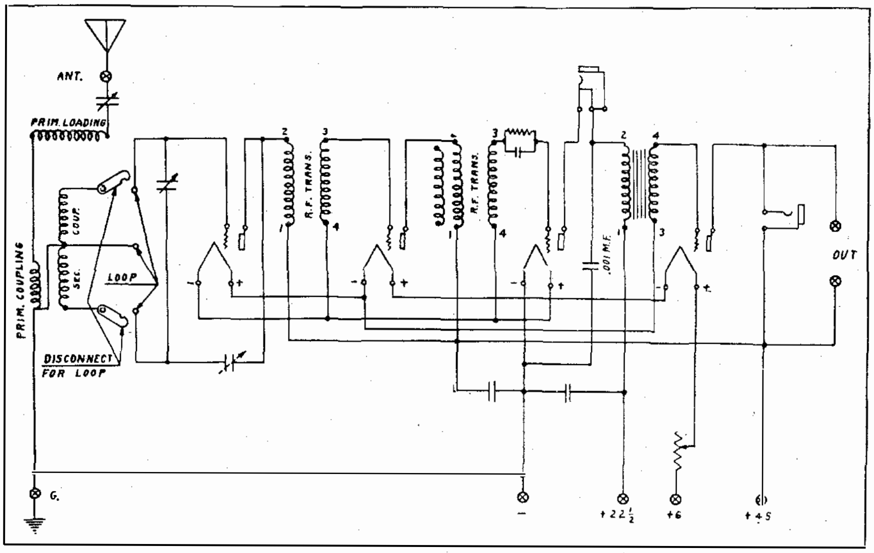


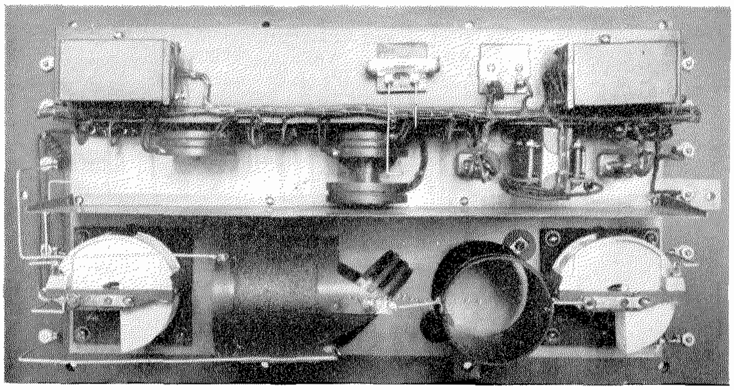
Figure 2—Motor Generator Set



Radio Receiver—Front



Radio Receiver—Circuit Diagram



Radio Receiver—Rear

Figure 5—Radio Receiver Set

current of frequency 135 cycles per second which is interrupted by the Selector Key so as to produce a pre-arranged code of impulses. The Interrupter Unit consists of a vibrator on which the reed can be tuned by means of a small jockey-

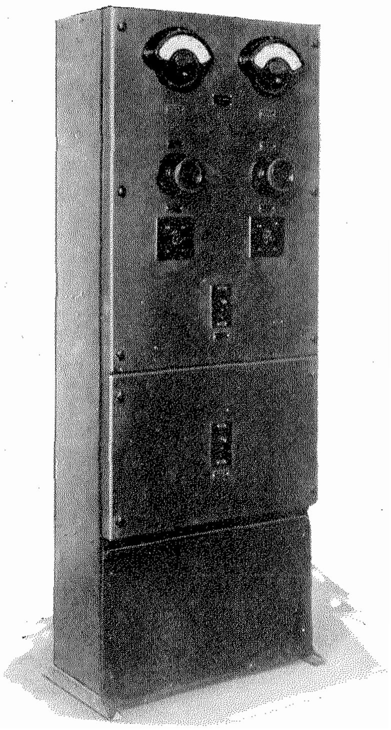


Figure 3—Power Panel—Front

weight. To eliminate as far as possible currents of other frequencies than that of 135 cycles per second, the resulting alternating current is passed through a transformer and then through a filter-circuit. The Selector Key consists of a toothed wheel driven by clockwork mechanism which makes and breaks two contact-springs in the output circuit of the interrupter Unit. By suitably allotting the code numbers, any one or all of a large number of stations can be called. The interrupted 135-cycle impulses are passed to the Talk-Ring Key. This is a double-throw key which in the "Talk" position disconnects the Interrupter Unit and connects the desk-stand and subscribers set to the Radio Transmitter. In the "Ring" position the subscribers set is disconnected and the interrupter unit is connected to the Radio Transmitter. At the same time the vibrator battery-circuit is completed. The 135-cycle impulses then modulate the steady radiated "carrier" in the same manner as described for speech.

At the receiving station the modulated "carrier" is received, amplified, and rectified as before, and the resultant impulses are then applied to the Signalling Unit containing an additional amplifier-valve for use if the signal strength requires it. The signal is then stepped up through a transformer efficient at 135 cycles, and is fed through a condenser to an alternating current relay, the reed of which is tuned to this frequency. The result is that undesired signals and atmospheric disturbances have practically no effect, and false calls are thus reduced to a minimum. The contacts of the A. C. relay operate a series of further relays and finally a selector-unit which when, and only when, the correct code of impulses is received, closes the circuit of a bell or other alarm system, which continues to operate until switched off by the receiving operator.

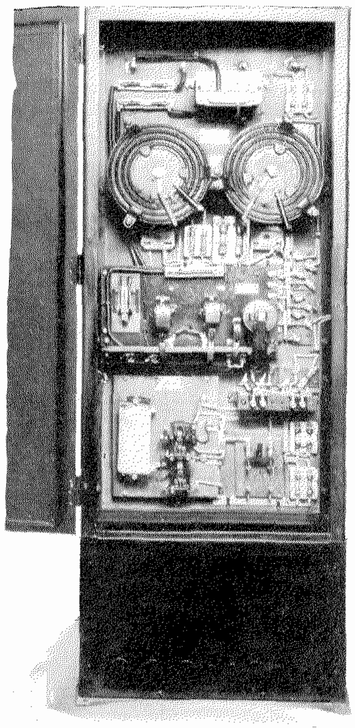
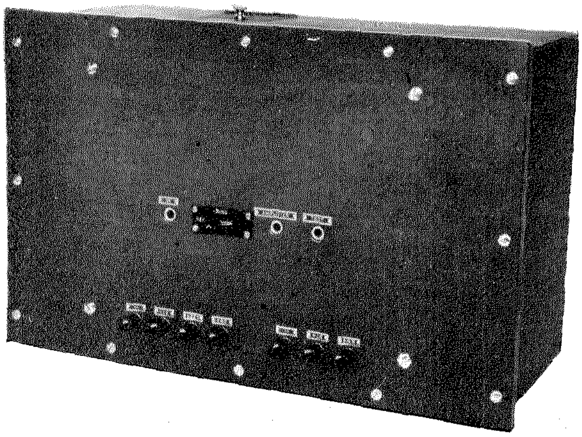


Figure 4—Power Panel—Rear

For Duplex working—i. e. simultaneous transmission and reception—a wave-trap consisting of an inductance and a capacity tuned to the transmitted wave-length, is interposed between the receiving antenna and the radio receiver at



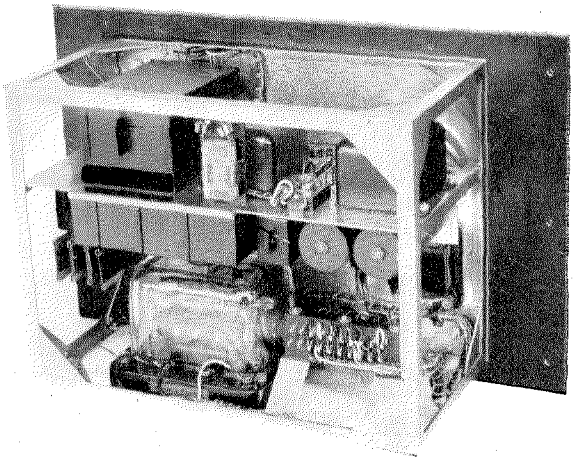


Figure 6—Signalling Unit—Front

Figure 7—Signalling Unit—Rear

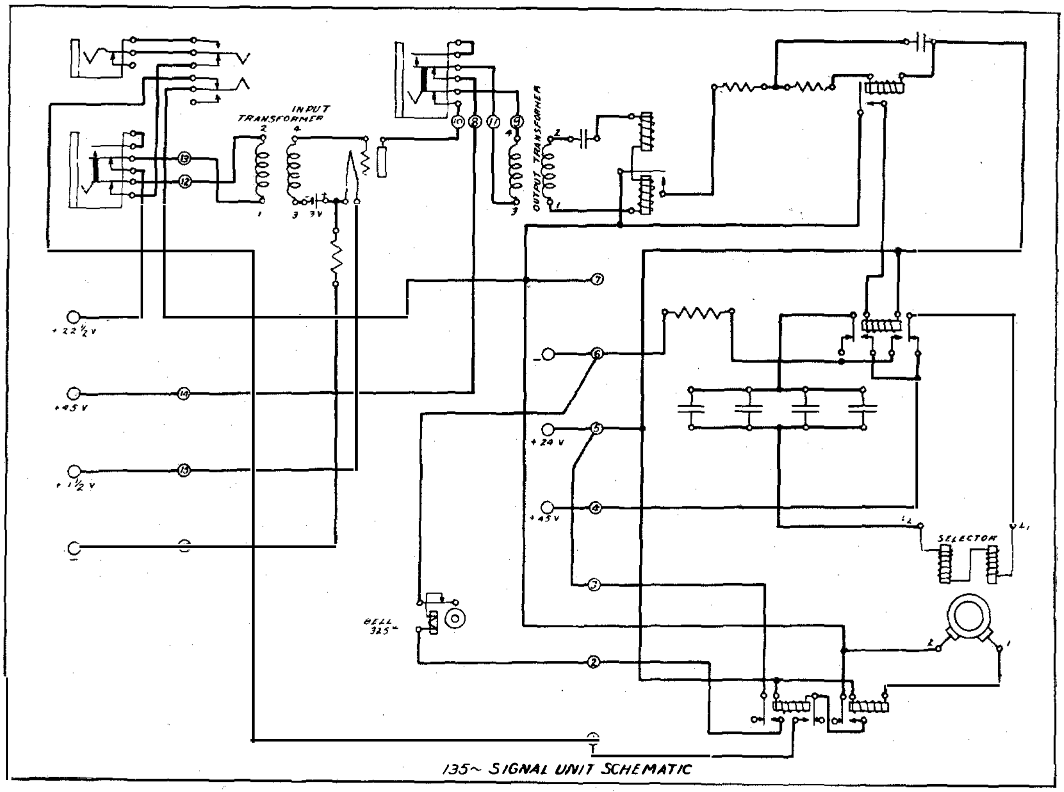


Figure 8—Signalling Unit—Wiring Diagram

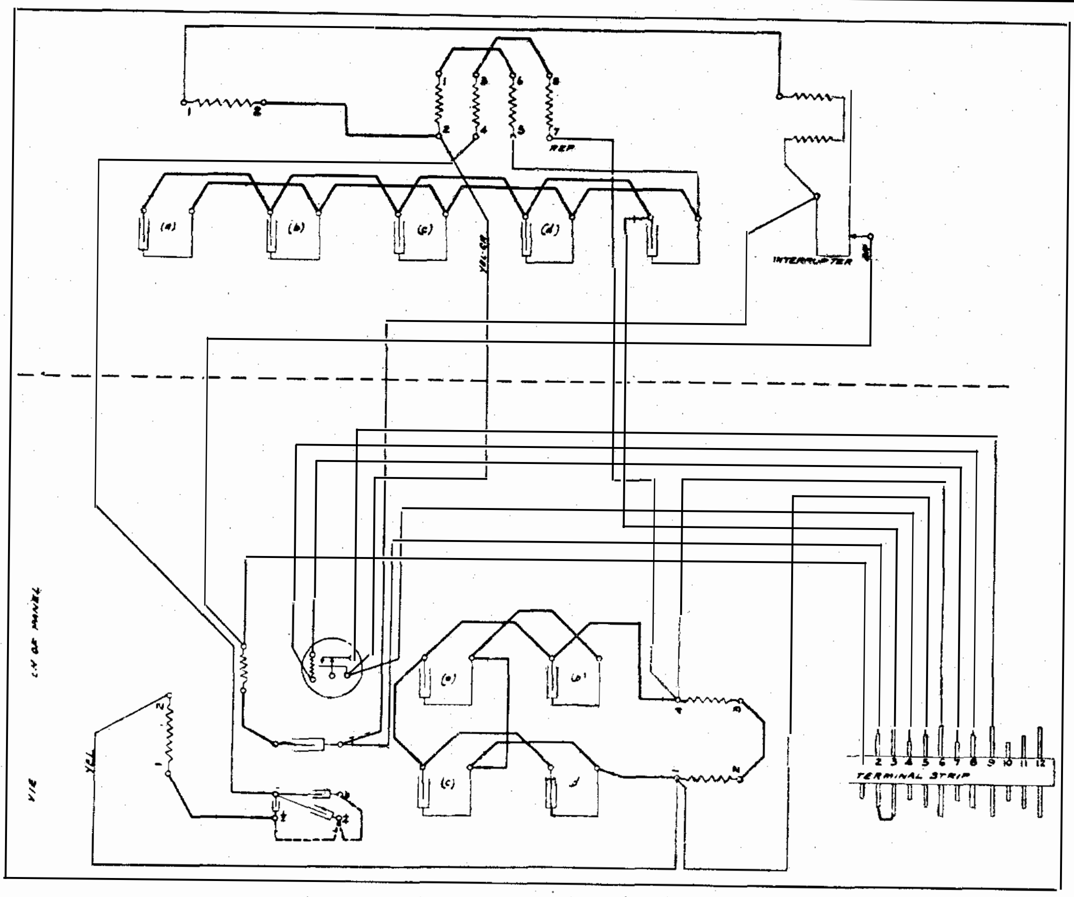


Figure 9—Interrupter Unit—Circuit Diagram

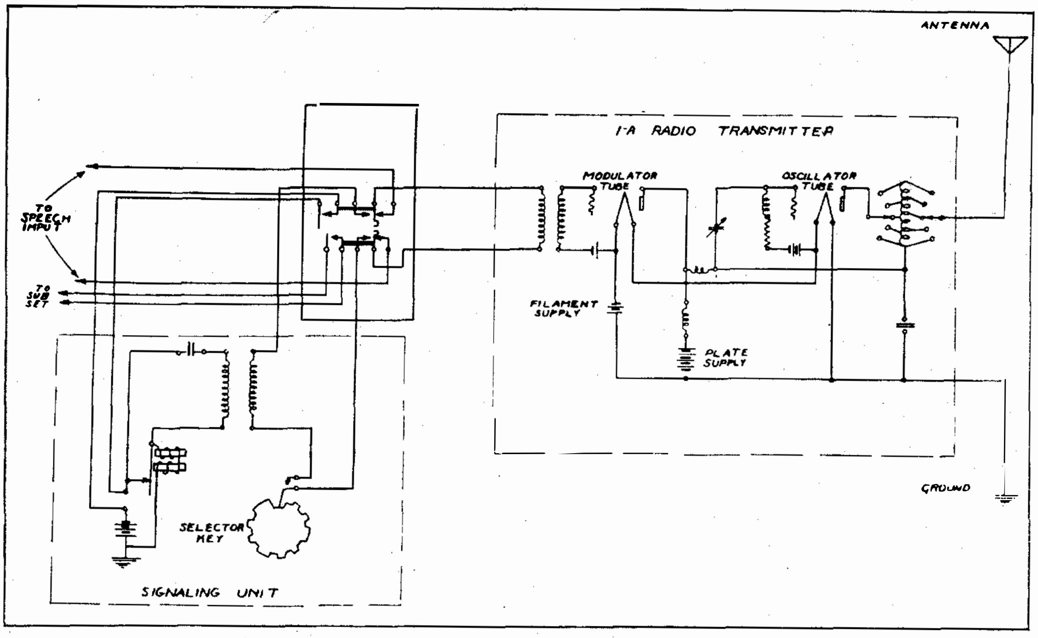


Figure 10—Selective Signalling System—Circuit Diagram
Automatic Signalling Equipment

each station. It is also necessary to use a wavelength difference of approximately 100 metres between the transmitter and receiver. The aerial relay is not required, but the transmitter as described above will work quite satisfactorily if the contacts which normally close when the switch is thrown to the "Transmit" side, are short circuited.

The two stations were installed under the most exacting conditions owing to inclement weather, the type of country, and the absence of any skilled labour. During the many transhipments of the apparatus enroute to the sites it was subjected to rough handling by the coolies. While being conveyed in native boats for part of the journey it was exposed to heavy rains and sea water. The "road" to the inland station was un-metalled, extremely rough, and only capable of carrying one-ton lorries. Despite these conditions, however the equipment suffered no serious damage. The masts are of tubular steel 120-ft. high and these also were given a very severe test during erection owing to the unskilled labour which had to be employed. At each station the earth-system consisted of a buried network of wires connected to metal plates distributed over an area approximately 100 yards in diameter. At the coast-station, a depth of six feet was sufficient, but at the inland station it was found necessary to excavate to twelve feet in order to reach a soft stratum in which to bed the earth system. The aerials were of the "T" type, at each station two 7–22's Silicon Bronze wires each 250-ft. long being used with a separation of ten feet. As no suitable power supply was available at either station a generator, driven by an internal combustion engine, was installed. To maintain a steady load on the driving engine, a regulating resistance was introduced into the field-circuit of the low-voltage generator when receiving. The control of the resistance was arranged to work automatically by the aerial relay so as to be suitable with unskilled operators.

Regular Commercial Communication is established between the two stations and also between each station and a spark station about 150 miles distant from each. There is a distinct shielding effect from the hills in proximity to the inland station, but no difficulty is experienced in maintaining permanent communication even in daylight during the summer months. Several non-technical members of the staff have been instructed in the operation of the equipments with complete success, although an unskilled man was in charge of the power room.

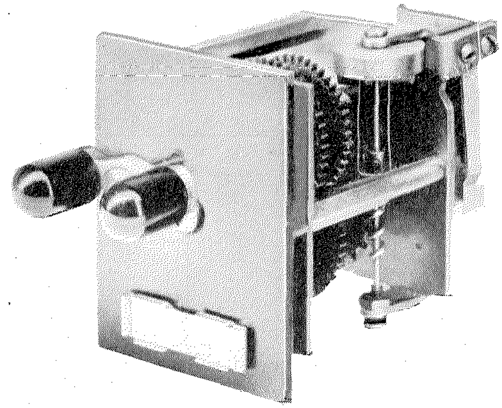


Figure 11—Selector Key

The Automatic Calling System operates satisfactorily and is not affected by atmospheric interference of normal intensity. By using this calling-system it has been possible to overcome the necessity for the operator to be in close attendance. It suffices for him to be within hearing of the calling bell.

[1]For description of Radio Telephone Signalling, Low Frequency System, see Electrical Communication V. 2, April, 1924.

Panel Type Machine Switching System in the United States

By H. P. CLAUSEN

Engineering Department, International Standard Electric Corporation

EARLY in 1922, the Western Electric Company, Inc., completed the installation of the first panel type machine switching system in Omaha, Nebraska, and, during 1925 the 500,000 line mark in the installation of this type of equipment by the Bell System was passed. According to present plans, the installation of over 750,000 lines of panel type equipment will have been completed in 1927. In view of the large number of lines in actual operation and scheduled for completion, it is the purpose of this article briefly to outline the progress made in the installation of this system and the program for the next two years as well as to indicate some of the operating results obtained.

On the basis of the program of 750,000 lines decided upon for completion in 1927, the following cities will be served by panel type equipment.

Location	Approximate No. of Lines
Metropolitan Area of New York City, including Mount Vernon and Brooklyn	300,000
Philadelphia (Pennsylvania) Area	100,000
Boston (Massachusetts) Area	80,000
Seattle (Washington) Area	44,000
St. Louis, Missouri	38,000
Newark (New Jersey) Area	37,000
Pittsburgh, Pennsylvania	28,000
Chicago, Illinois	27,000
Kansas City, Missouri	27,000
Detroit, Michigan	23,000
Cleveland, Ohio	16,000
Baltimore, Maryland	16,000
Omaha, Nebraska*	14,000
Providence, Rhode Island	14,000
Atlanta, Georgia	8,000
Buffalo, New York	5,000
	777,000

* First city in which a two office unit was installed.

Following the Omaha, Nebraska, installation, the Pennsylvania office was placed in operation by the New York Telephone Company in New York City. The original installation of this office provided for 6,384 lines. At the present time, it comprises over 9,000 lines and gives service to something over 23,600 stations. This large number of stations per line, approximately three, is due to the importance of the private branch exchange development in this district.

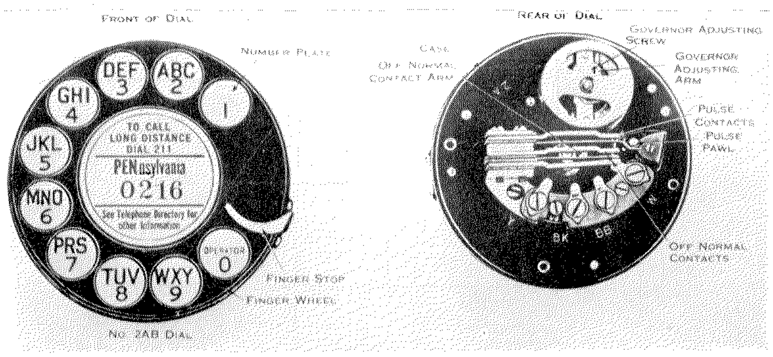


Figure 1—Subscriber's Dial

Description of Equipment

Before describing a group of exchanges in operation in New York City, the following brief reference to the more important features of the panel type system may be helpful.

Argent Co, 1400 Bway..............GRE eley 5733
Argentina Brazil & Chile Shipping Co
70 Wall.HAN over 0307
Argentine Genl Consulate, 17 Batry pl..REC tor 6946
Argentine Impt & Expt Corp, Prod Ex...BRO ad 1768
Argentine Mercantile Corp, 42 Bway.....BRO ad 5066
Argentine Naval Commission, 2 W 67..COL mbus 5623
Argentine Quebracho Co, 80 Maiden la....JOH n 1652
Argentine Railway Co, 25 Broad.......BRO ad 1383
Argentine Trading Co, 1164 Bway......MAD Sq 1871
Argeres Bros, Restrnt, 86 6th av......SPR ing 5337
Argero A, Grocer, 119 9th av........CHE lsea 6255
Arghis A, Tobacco, 74 Wall.........HAN over 6311
Argirople Theodore, Jwlr, 406 8th av..FAR ragut 9772
Argo Packing Corpn, 705 Greenwich...FAR ragut 4505
Argon Dress Co, 24 E 12..........STU yvsnt 2011
Argonaut Supply Corp, 50 Union sq..STU yvsnt 7476
Argonne Steamship Co, 17 Battery pl...REC tor 2493
Argos Ad-Art Co, 1133 Bway........FAR ragut 5986
Argosy The (A Pub), 280 Bway......WOR th 8800

Figure 2—Section of New York City Telephone Directory

Figure 1 illustrates the type of dial adopted for service in New York City. This particular illustration shows the designation plate of a telephone served by the Pennsylvania office.

Figure 2 is a section of a New York City directory showing how the exchange names and numbers are designated. When a call is desired for say the "Argent Company, Greeley 5513," the subscriber dials the letters "G," "R" and "E," and then the numerals "5513." When making the call, the subscriber does not switching operator to complete the connection with the manual subscriber's line in the usual manner, by means of a connecting plug placed into the multiple jack of the called subscriber's line.

When a call originates in a manual office for a subscriber located in a machine switching area,

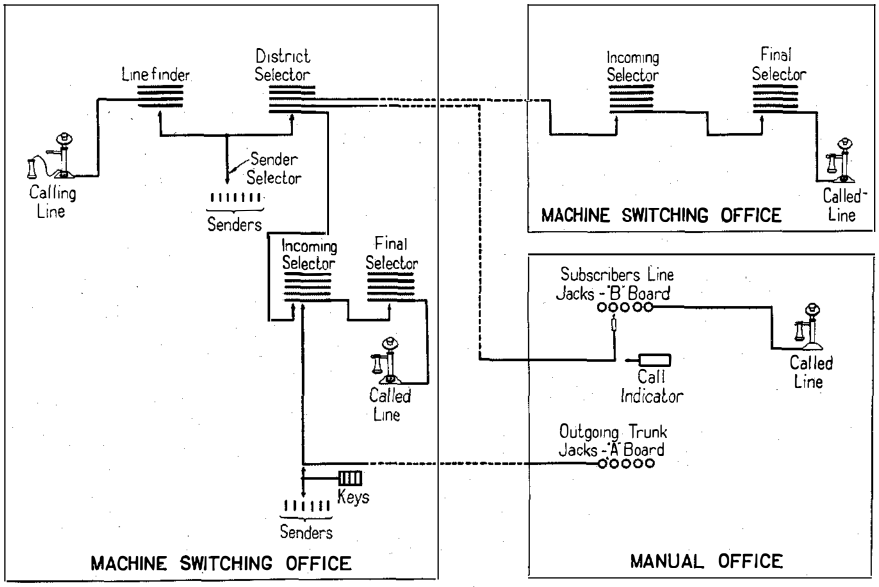


Figure 3—Diagram Showing Connections from Machine Switching to Machine Switching, Machine Switching to Manual and Manual to Machine Switching

have to know whether the number called is connected to a manual or machine switching exchange.

Figure 3 is a diagram showing the connections between machine switching offices, and between machine switching and manual offices.

Figure 4 gives a general idea of the appearance of a group of typical selector frames.

Where machine switching offices are installed in multi office cities served by manual equipment, it is necessary to route calls from machine switching to manual exchanges, and means have been developed by which the number dialed by a calling subscriber will be displayed automatically by a call indicator installed before a switching operator in the manual office.

Figure 5 shows the call indicator equipment as a part of the incoming trunk position. It will be noted that the numbers dialed by the calling subscriber are displayed in the indicator panel. Their appearance permits the manual the A operator extends the call through to a cordless B operator in the machine switching office. Figure 6 shows a number of cordless B positions. As stated before, the subscriber need not know whether the line wanted connects to a manual or machine switching exchange.

The attending cordless B operator, upon receiving instructions from the originating A operator, sets up on a set of keys the digits of the desired number and the machine switching mechanism then connects the trunk line with the line of the called subscriber.

Figure 7 shows the battery room for a group of two 10,000 line units, and Figure 8 gives a typical view of the machinery and control equipment required for a two unit office.

Ashland-Caledonia Offices

A rather interesting installation placed in operation by the New York Telephone Company during 1924 is the Ashland-Caledonia

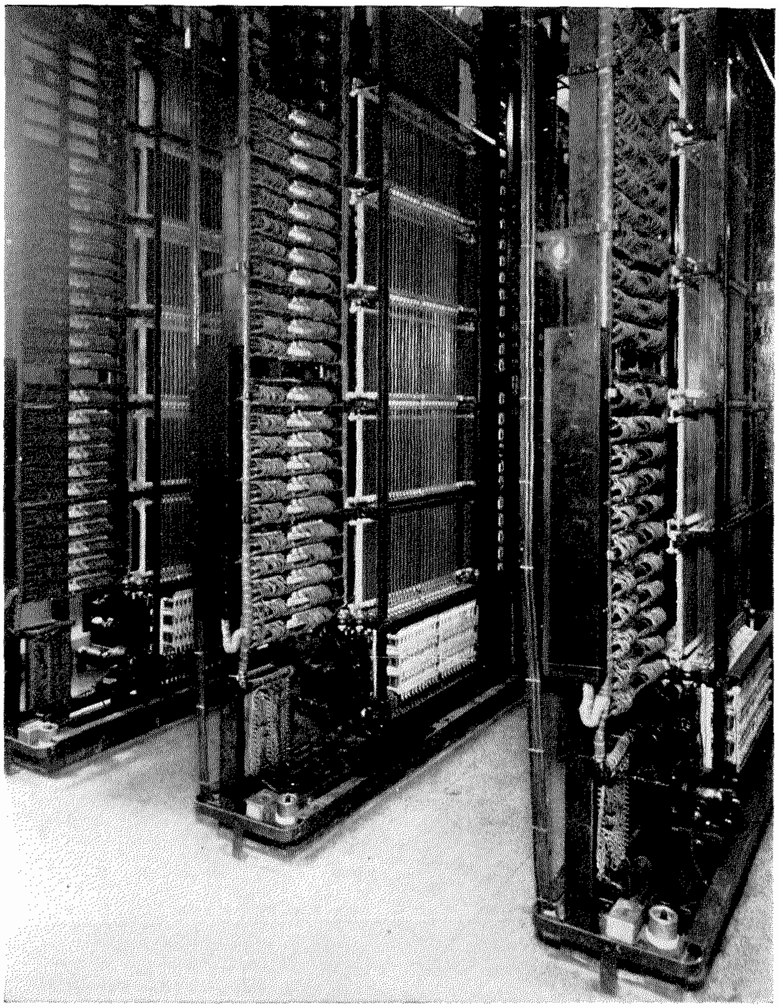


Figure 4—Group of Typical Selector Frames

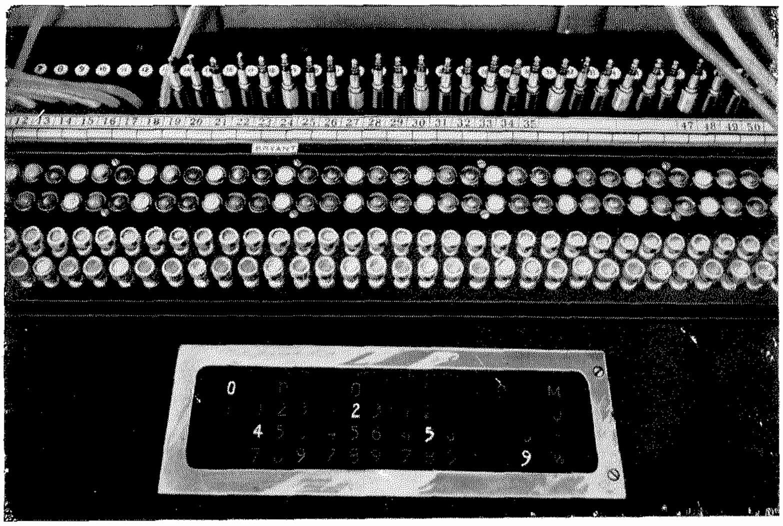


Figure 5—Incoming Trunk Position in a Manual Office Arranged for Call Indicator Operation

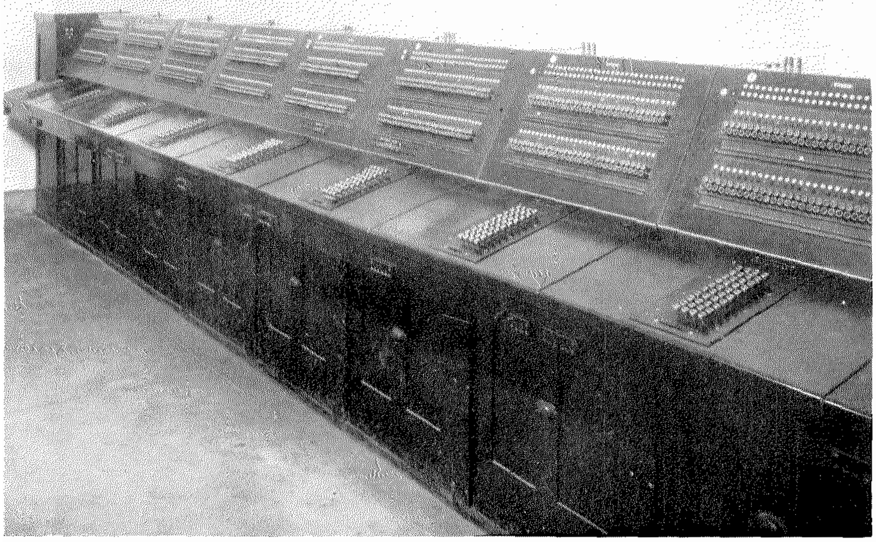


Figure 6—Cordless "B" Positions in Machine Switching Office

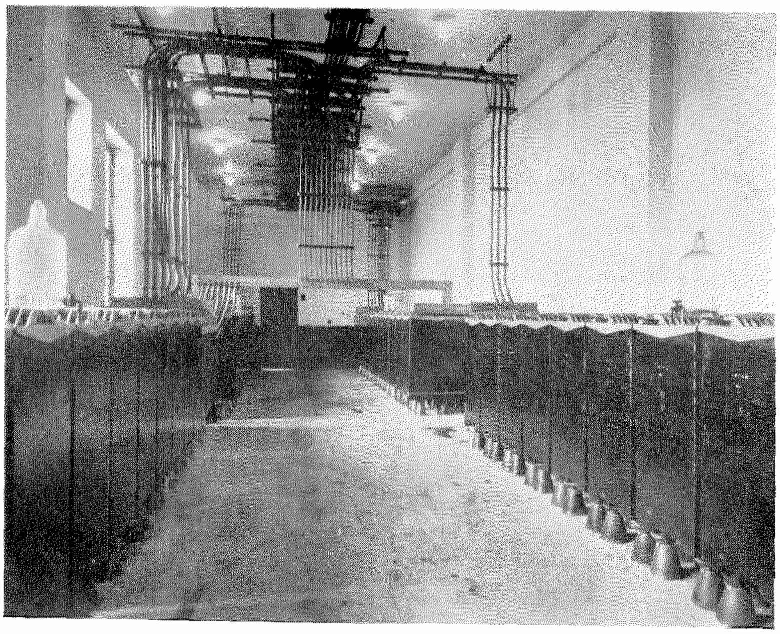


Figure 7—Battery Room for Two 10,000 Line Units

group which consists of two machine switching exchanges installed in the same building with a manual exchange at East 30th Street, New York City. Each machine switching office is equipped for 10,000 line terminals.

The Ashland office is a high grade business exchange; only 2% is residence development. The Caledonia exchange serves about 14.1% residence development. The total of the Ashland and Caledonia residence development amounts to 7.9%.

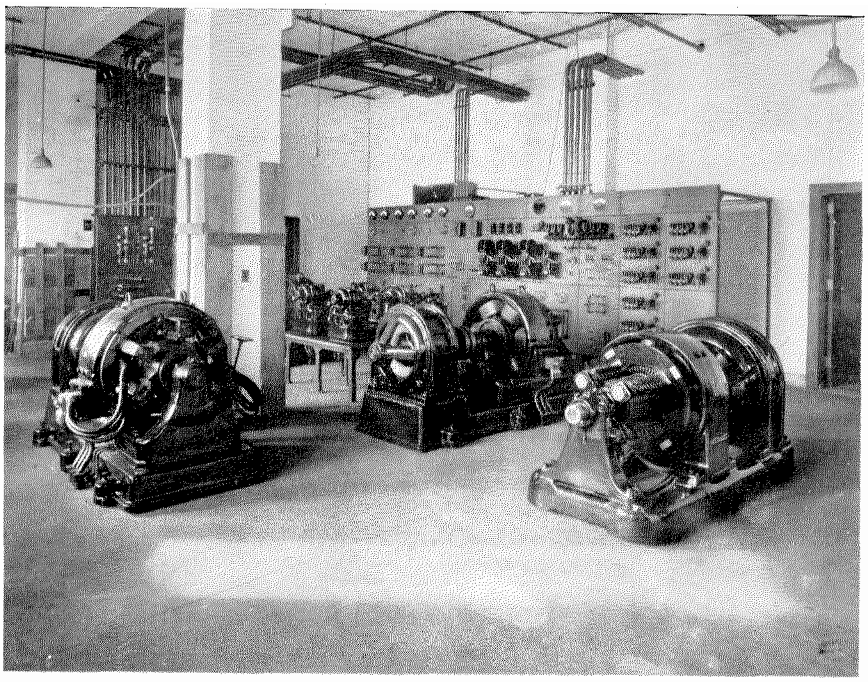


Figure 8—Power Machine and Control Equipment for Two Unit Office

The private branch exchange development is very high. The two machine switching units have a total of 15,211 lines in service; 6,630 (43½%) of the lines connect to private branch exchanges, and the balance of 8,581 lines serve main line telephones.

The total number of stations in the two exchanges is 34,842, of which approximately 70% are located in private branch exchanges.

When the manual office at East 30th Street, known as Lexington, is included, there is a total of 20,749 lines and 42,657 stations in service. Of the lines in the group of three exchanges, 73½% are connected to the machine switching units, and the stations served from these units amount to approximately 82% of the total.

Another interesting fact about this group of three exchanges is that comparing the manual with the machine switching exchanges, 91% of the private branch exchange lines and stations are connected to the machine switching units.

The line and station equipment of the three exchanges, substantially correct as of June, 1925, are tabulated in Table I.

Traffic Information

Preliminary to the consideration of traffic information relating to the Ashland and Caledonia exchanges, it may be of interest to note certain figures taken from the installation records.

In order to provide for the trunking service from the two units to other local exchanges in the metropolitan area, provision was made for slightly under 2,800 trunks, and in order to carry the outgoing toll and long distance traffic, a special trunk equipment of 200 lines was provided. The incoming local service trunks amount to slightly under 3,800 and the calls

TABLE I

Machine Switching System

	Ashland		Caledonia		Total	
	Lines	Stations	Lines	Stations	Lines	Stations
Main Line	3006	2989	5575	5520	8581	8509
Extension		1256		1781		3037
PBX Lines	3937	13446	2693	9851	6630	23296
	6943	17691	8268	17152	15211	34842

	Manual System		Machine Switching and Manual Systems	
	Lexington		Ashland, Caledonia and Lexington	
	Lines	Stations	Lines	Stations
Main Line	4887	4865	13468	13374
Extension		545		3582
PBX Lines	651	2405	7281	25701
	5538	7815	20749	42657

TABLE II

	Ashland	Caledonia	Total
No. of Lines	6805	8144	14949
Originating Calls—			
Busy Hour Calling Rate	2.08	1.56	1.74
Busy Hour Calls	14200	12700	26900
Total Calls Per Day	103700	102000	205700
Per Cent. Busy Hour Calls to Calls Per Day	13.7	12.47	13.1
Originating Calls—			
Busy Hour Calls			
Toll	646	420	1066
Long Distance	43	34	77
Local	13511	12246	25757
Total	14200	12700	26900
Total Calls Per Day			
Toll	4100	3515	7615
Long Distance	270	275	544
Local	99330	98210	197540
Total	103700	102000	205700
Incoming Calls—			
Busy Hour Calls			
Long Distance and Toll	970	683	1653
Local	16030	14567	30597
Total	17000	15250	32250
Total Calls Per Day			
Long Distance and Toll	6500	4180	10680
Local	117800	117220	235020
Total	124300	121400	245700
Originating Calls—Total	103700	102000	205700
Incoming Calls—Total	124300	121400	245700
Grand Total	228000	223400	451400

from toll and long distance exchanges are handled by 190 trunks.

An interesting feature of the Ashland-Caledonia-Lexington installations is the provision of a main distributing frame common to the three exchanges. The verticals of this frame are 400 lines high and the entire frame contains 58 verticals, thus providing for a total of 23,200 lines.

The traffic results shown in Table II are taken from records substantially correct as of August 1, 1925. The figures convey fairly well the number of calls handled in the two machine switching exchanges.

The average number of originating calls per line, during the busy hour, for the two exchanges is 1.74. The total originating calls during the busy hour of the day is 26,900 which is approximately 13% of the total calls for the day.

The totals of the originating and incoming calls for the day, including toll and long distance, are 205,700 and 245,700 respectively, or a grand total of 451,400 calls in the two machine switching offices.

New York City Completed Installations and Program

There are now in operation, in the New York City metropolitan area, twenty-eight machine switching offices, and it is planned to increase this number of offices materially within the next five years.

Irregularities in Loaded Telephone Circuits

By GEORGE CRISSON

American Telephone and Telegraph Company

Synopsis: The development of long distance telephone transmission has made the question of line irregularities a matter of great importance because of their harmful effect in producing echo currents and causing the repeaters to sing.

The structure of coil-loaded circuits permits the calculation of the probability of obtaining an assigned accuracy of balance between line and network when certain data are known or assumed regarding the accuracy of loading coil inductance and section capacity.

Formulae are given and the results of calculations compared with measurements made on circuits of known accuracy of loading.

Introduction

THE application of repeaters to telephone circuits in which the speech currents in the two directions of transmission pass through the same electrical path, has caused considerable emphasis to be placed on the matter of making the telephone circuits as free as possible from irregularities. This paper aims to present the theory of the relation between the irregularities in coil loaded lines and the effects resulting therefrom, which have an important bearing upon the operation of two-way telephone repeaters.

The idea of applying the theory of probability to the problem of summing up the effects of many small line irregularities was first suggested in 1912 by Mr. John Mills. The effect upon repeater operation of impedance unbalance had been mathematically analyzed by Dr. G. A. Campbell; and the effect upon impedance of a single irregularity of any type had been investigated by Mr. R. S. Hoyt. Using a probability relationship which was pointed out by Mr. E. C. Molina, Mr. Mills developed a formula which gives the average or probable impedance departure in terms of average or probable irregularities in inductance or capacity, which served at the time of the engineering of the transcontinental line (1913–14) and for some years after.

With the rapid growth of repeatered circuits in cable it became necessary to calculate what fraction of a large number of essentially similar lines would give a definite impedance unbalance at a given frequency. The necessary mathematical work to indicate the conditions for a large group of similar lines was recently carried out independently by Messrs. H. Nyquist and R. S. Hoyt.

The theory which has thus been evolved over a period of years is now presented in a manner which it is hoped will be found relatively simple and useful. Various charts are given which should be of material aid in the application of the theory. There are also given the results of some experiments made on cable circuits in which comparison is made between the impedance departures of the circuits as obtained by direct measurement with the departures as computed from data covering the individual irregularities. These impedance departures are expressed as "Return Losses," the meaning of which is explained below. The agreement is shown to be close enough to constitute a good check as to the correctness of the underlying theory.

Magnitude of Reflected Current

In Figure 1, are shown three regular [1] telephone lines of the same types beginning at a certain point A. The first line L_1 passes through another point B and continues on to infinity. The

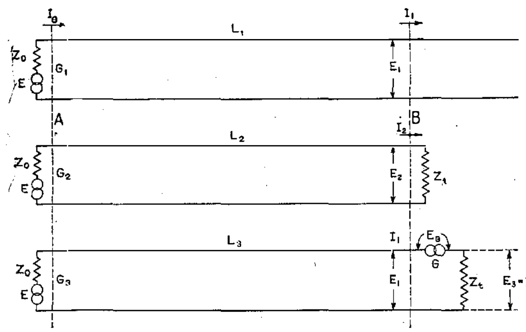


Figure 1

second line L_2 terminates at B where it is connected to an impedance Z_t which differs from the characteristic impedance Z_o of the three lines, thus constituting an irregular termination. The third line L_3 also terminates at B where it is

[1] In this paper the term "regular" implies that a telephone line is free from electrical irregularities.

connected to an impedance Z_t and a generator G of zero impedance whose purpose will be described later. At the sending end A each line is provided with one of three identical generators, G_1, G_2, G_3, having an impedance equal to Z_o the characteristic impedance of the line. The internal voltages of these generators are all equal and represented by E. The generator G_1 impresses a voltage $E_o=\frac{1}{2}E$ upon the sending end of the line L_1 and causes a current I_o to flow into it. The voltage and current waves are propagated regularly over the line to the point B where they set up a potential difference E_1 between the conductors and cause a current I_1 to flow. E_1 and I_1 are smaller in magnitude and later in phase than E_o and I_o because of the losses and finite velocity of transmission of the line L_1. These quantities have the relation

$$\frac{E_o}{I_o}=\frac{E_1}{I_1}=Z_0 \qquad (1)$$

since the line is regular.

In the second line L_2 a different set of conditions exists. In this case, the voltage E_2 and the current I_2 produced at B by the generator have the relation

$$\frac{E_2}{I_2}=Z_t. \qquad (2)$$

When the e.m.f. of the generator G is zero, the conditions in the third line L_3 are the same as in L_2 but by adjusting the phase and magnitude of the e.m.f. of this generator the current in the terminal impedance Z_t can be made equal to I_1 and the drop across this impedance becomes

$$E_3=I_1Z_t. \qquad (3)$$

Under these conditions the current I_1 flows at the end of the line L_3 and the potential difference E_1 exists between the conductors at this point. The line L_3 is then in the same condition as the line L_1 between the points A and B. When the waves arrive at B over the line L_3 the generator boosts or depresses the voltage at the terminus of the line by just the amount necessary to cause the terminal apparatus to take the desired current. Then the e.m.f. of the generator G is

$$E_G=E_3-E_1. \qquad (4)$$

Removing the e.m.f. of the generator G makes the conditions in line L_3 identical with the conditions in L_2, but removing this e.m.f. is the same thing as introducing another e.m.f. $-E_G$ in series with the generator which annuls its e.m.f. E_G. This e.m.f. $-E_G$ causes a current I_3 to flow back into the line

$$I_3=-\frac{E_G}{Z_o+Z_t}. \qquad (5)$$

Substituting from equations (1), (3) and (4) above

$$I_3=\frac{Z_o-Z_t}{Z_o+Z_t}I_1. \qquad (6)$$

That is, the effect of connecting an impedance Z_t to the end of a line of characteristic impedance Z_o is to return toward the source a current whose value is $\frac{Z_o-Z_t}{Z_o+Z_t}$ times the current that would exist at the terminus if the line were regularly terminated. The ratio between the reflected and the incident current is known as the "reflection coefficient," the value of which is expressed as follows:

$$r=\frac{I_3}{I_1}=\frac{Z_o-Z_t}{Z_o+Z_t}. \qquad (7)$$

This ratio can also be expressed in transmission units (TU). When expressed in TU this relation will be referred to in this paper as the "Transmission Loss of the Returned Current," or, briefly, as the "Return Loss."

If a condition occurs in a line which causes the impedance at any point to differ from the characteristic impedance it has the same effect as an irregular termination.

Return Loss at a Repeater Due to a Single Irregularity

Figure 2 shows a No. 21-type repeater connected between a line and a network whose

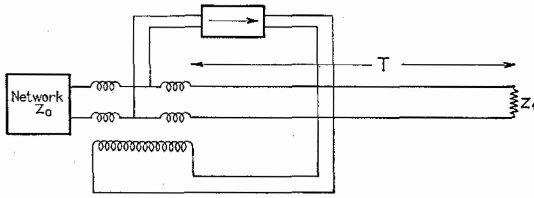


Figure 2

impedance is exactly equal to the characteristic impedance Z_o of the line. If the line is perfectly regular the repeater will be perfectly balanced and the gain can be increased indefinitely without causing the repeater to sing.

Assume now that the line is terminated by some apparatus having an impedance Z_t at a distance from the repeater such that the transmission loss of the intervening line is T TU. If a wave of current having a certain magnitude leaves the repeater, it is reduced in strength by T TU when it reaches the terminus. Of this current, a certain amount is transmitted back toward the repeater, suffering a further loss of T TU on the way; consequently, the relation expressed in TU between the strength of the currents leaving and returning to the repeater, that is, the return loss at the repeater, is given by the equation

$$S=20\log_{10}\frac{Z_o+Z_t}{Z_o-Z_t}+2T. \qquad (8)$$

If the gain of the repeater, expressed in TU, is equal to or greater than S the repeater will sing provided the returning current has the correct phase relation to reinforce the original wave. For this reason the term "Singing Point" has frequently been applied to the quantity S which is called "Return Loss" in this paper.

If the line is shortened until the impedance Z_t is connected directly to the repeater terminals, the transmission loss T between the repeater and the irregularity is reduced to zero and the return loss becomes

$$S=20\log_{10}\frac{Z_o+Z_t}{Z_o-Z_t}. \qquad (9)$$

Return Loss of Irregular Lines

In practice, lines are never perfectly regular. Not only is it impracticable to build apparatus which would form a perfectly regular termination for a line, but there are numerous causes of irregularity in the lines themselves, each one of which is capable of reflecting a portion of the waves which traverse the line. These irregularities can be kept smaller than any specified amount if sufficient care is used in building and maintaining the line but they cannot be entirely eliminated; consequently, if a length of actual line is terminated regularly by a network of impedance Z_o, the return loss will be high if the line is carefully built and low if it contains large irregularities. The return loss of such a line, when terminated regularly by a network is a measure of the quality of the line from the standpoint of repeater performance. In measuring the return loss of a line it is necessary that a rather long section of the line be available so as to include all irregularities near enough to have an appreciable effect upon the result. If the section measured is too short, the result will be too high because only a few irregularities will be included.

Calculation of the Return Loss of Coil Loaded Lines

Owing to the facts that the inductance of coil loaded lines is concentrated principally in the loading coils and the capacity is divided into elements of finite size by the loading coils and, further, that the electrical irregularities are due principally to the deviations of the inductance of the coils and the capacity of the sections from their average values for the line, it is possible to calculate by a fairly simple method the value of the return loss of a coil loaded line if the representative values of these deviations and the electrical properties of the line are known or assumed.

Since the return loss depends upon the accidental combination of a large number of unbalance currents there will not be one definite value applying to all circuits, but an application of the theory of probabilities makes it possible to compute what return loss will probably be surpassed by any assigned fraction of a large group of lines having the given deviations.

The method of calculating the return loss of coil loaded lines will now be described. The symbols used in this description and their meanings are given in the following table:

TABLE I

A	= Attenuation Factor per Loading Section = Ratio of the Current Leaving a Loading Section to the Current Entering it.
C	= Normal Capacity per Loading Section in Farads.
F	= Fraction of a Large Group of Lines.
f	= Any Frequency for which a Return Loss is to be Found.
f_c	$=\frac{1}{\pi\sqrt{LC}}$ = Critical or Cutoff Frequency of the Line.
H_C	= Representative[2] Deviation of the Capacity of Loading Sections.

h_C = Deviation of the Capacity of a Particular Loading Section.

H_L = Representative[2] Deviation of the Inductance of Loading Coils.

h_L = Deviation of the Inductance of a Particular Loading Coil.

H = $\sqrt{H_C^2+H_L^2}$ = Representative[2] Combined Deviation.

I_o = Current Entering the Line.

I' = Representative[2] Total In-Phase Returned Current at the Sending End.

I'' = Representative[2] Total Quadrature Returned Current at the Sending End.

I_F = Value of Returned Current which will be Exceeded in a Specified Fraction F of a Large Group of Lines.

i' = Total In-Phase Current at the Sending End of the Line.

i'' = Total Quadrature Current at the Sending End of the Line.

$i_1, i_2, i_3, --- i_n$ = Currents Returned from the 1, 2, 3, ----- and nth Irregularities.

$i_1', i_2', i_3', ----- i_n'$ = In-Phase Components of $i_1, i_2, i_3, --- i_n$

$i_1'', i_2'', i_3'', ----- i_n''$ = Quadrature Components of $i_1, i_2, i_3, --- i_n$

k = $\sqrt{\frac{L}{C}}$ = Nominal Characteristic Impedance of the Line.

L = Normal Inductance of a Loading Coil.

n = Number of Irregularities.

P = Probability Function for the Absolute Value of the Total Returned Current at the Sending End.

p' = Probability Function of the Total In-Phase Returned Current.

R_C = Representative[2] Reflection Coefficient at Capacity Irregularities.

R_L = Representative[2] Reflection Coefficient at Inductance Irregularities.

r_C = Reflection Coefficient at a Capacity Irregularity.

r_L = Reflection Coefficient at an Inductance Irregularity.

$r_1, r_2, r_3, --- r_n$ = Reflection Coefficient at the 1, 2, 3, --- nth Irregularities.

S = Return Loss, Infinite Line.

S_n = Return Loss, Finite Line.

S_A = Attenuation Function.

S_F = Distribution Function.

S_H = Irregularity Function.

S_w = Frequency Function.

T = Transmission Loss in a Finite Line.

$\Theta_1, \Theta_2, \Theta_3, ---- \Theta_n$ = Phase Angles of the Currents at the Sending End Returned by the 1, 2, 3, --- nth Irregularities.

w = f/f_c.

[2] The "representative" deviation or current is an index of the magnitude of the deviation or current that may be expected in accordance with the laws of the distribution of errors. It corresponds to the root-mean-square error. It must not be confused with the "effective" or r.m.s. value of a particular alternating current. The meaning of the term as used here is more completely explained in the paragraph following equation (24).

Reflection at a Coil Irregularity

If a loading coil has too much or too little inductance, the effect is the same as if a small inductance $h_L L$ had been added to or taken away from the coil. The reactance of this increment is $2\pi f L h_L$. The additional reactance has the same effect wherever it may occur in the load but it is somewhat simpler to assume that the increment is introduced at mid-coil. Within the useful range of telephonic frequencies, the mid-coil impedance of a loaded line is given closely by the expression $k\sqrt{1-w^2}$.

In equation (7) $Z_o - Z_t$ corresponds to $2\pi f L h_L$ while $Z_o + Z_t$ is approximately equal to $2k\sqrt{1-w^2}$ when the irregularity is small, consequently:

$$r_L = \frac{\pi f L h_L}{k\sqrt{1-w^2}} \qquad (10)$$

and, substituting for f and k their equivalents obtained from relations given in Table I,

$$r_L = h_L \frac{w}{\sqrt{1-w^2}}. \qquad (11)$$

Reflection at a Spacing Irregularity

If a loading section has too much or too little capacity, the effect, neglecting conductor resistance, is the same as if a small bridged capacity $h_C C$ were added to or removed from the line. The effect is the same for any point in the section, but it is somewhat simpler to assume that the additional capacity is applied at mid-section. The reactance of the added capacity is $\frac{1}{2\pi f h_C C}$ and the mid-section impedance is, closely, $\frac{k}{\sqrt{1-w^2}}$.

When the bridged reactance is large compared with the line impedance, the reflection coefficient r_c is given closely by the equation

$$r_C = \frac{1}{2}\frac{\frac{k}{\sqrt{1-w^2}}}{\frac{1}{2\pi f h_C C}} \qquad (12)$$

from which, substituting the values of f and k as before

$$r_C = h_C \frac{w}{\sqrt{1-w^2}} \qquad (13)$$

which is identical in form with equation (11) above.

Approximations Made in Deriving R_L and R_C

The expressions for the mid-coil and mid-section impedances used above in deriving equations (10) and (12) are simple approximations which take no account of the effects of the resistance of the line conductors and loading coils, leakage between conductors or distributed inductance. The errors due to these effects are negligible in the important parts of the frequency range involved in telephone transmission when the types of loading and sizes of conductors now commonly used are considered. The errors due to these causes tend to increase for frequencies which are very low or which approach the cutoff frequency. For accurate calculations relating to very light loading applied to high resistance conductors it would be desirable to take into account the effects of resistance. Because the use of the precise expressions would greatly complicate this discussion and would probably serve no very useful purpose at this time, the approximations given above are used.

Current Returned to the Sending End of the Line

Consider first a line having only one kind of irregularity as, for example, one in which only the loading coils are assumed to vary from their normal values. If a current I_o enters such a line, a current i_1 is returned to the sending end from the first irregularity (assumed to be very near the sending end)

$$i_1 = r_1 I_o \tag{14}$$

a second current

$$i_2 = A^2 r_2 I_o \tag{15}$$

is returned from the irregularity located at a distance of one loading section away from the sending end, since the current is reduced by the factor A in going to the irregularity and again in returning.

Similarly, a current

$$i_n = A^{2(n-1)} r_n I_o \tag{16}$$

is returned from the nth irregularity.

The first current will return to the sending end with a certain phase angle Θ_1 with respect to the initial current, the second with a phase angle Θ_2, etc. Each returned current may be resolved into two components, one in phase with the initial current and one in quadrature.

The in-phase components of the currents are then:

$i_1' = I_o r_1 \cos \Theta_1$ from the first irregularity. (17)

$i_2' = I_o r_2 A^2 \cos \Theta_2$ from the second irregularity (18)

$i_3' = I_o r_3 A^4 \cos \Theta_3$ from the third irregularity. (19)

$i_n' = I_o r_n A^{2(n-1)} \cos \Theta_n$ from the nth irregularity. (20)

and the quadrature components are:

$i_1'' = I_o r_1 \sin \Theta_1$ from the first irregularity. (21)

$i_2'' = I_o r_2 A^2 \sin \Theta_2$ from the second irregularity. (22)

$i_3'' = I_o r_3 A^4 \sin \Theta_3$ from the third irregularity. (23)

$i_n'' = I_o r_n A^{2(n-1)} \sin \Theta_n$ from the nth irregularity (24)

Now the deviations of the inductance (and capacity) resemble the errors of measurement discussed in many text books dealing with the precision of measurement, consequently, they can be studied and their effects combined by the same mathematical law.

Examination of measurements of the inductance of large numbers of loading coils and the capacities of the pairs and phantoms in many reels of cable have shown that the most reasonable assumption is that the deviations of inductance and capacity follow the "normal" law of the distribution of errors.

The deviation at each irregularity is not known but it is possible to derive from the measurements of the inductance of large numbers of loading coils (and the capacity of many lengths of cable) representative values for these deviations similar to the "mean error." Because of the way in which the effects of irregularities combine, this *representative deviation* is taken as the square root of the mean of the squares of the deviations (r.m.s. deviation) of the individual coils. If the average deviation of a large group of coils is known, but the individual deviations are not, it may be multiplied by 1.2533 to obtain the representative deviation on the assumption that the deviations follow the normal law of errors.

If then the representative deviation H_L is substituted for the particular deviation h_L in equation (11), we obtain the representative reflection coefficient

$$R_L = H_L \frac{w}{\sqrt{1-w^2}}. \tag{25}$$

Now in the usual case where no effort is made to select the loading coils and so obtain a special distribution of the deviations the representative deviation and the representative reflection coefficient are the same for each coil. Substituting R_L for r_1, r_2, etc., in equations (17) to (24) each

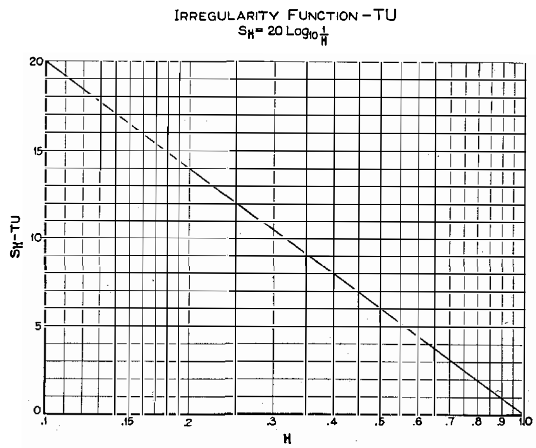


Figure 3

equation gives the representative value, at the sending end of the line, for the current reflected from the corresponding irregularity.

According to the laws for the combination of deviations which are demonstrated in treatises dealing with precision of measurements the representative value of the current due to all the irregularities would be the square root of the sum of the squares of the representative values of the different currents taken separately, consequently the representative in-phase current is

$$I' = I_o R_L \sqrt{(\cos^2\Theta_1 + A^4\cos^2\Theta_2 + A^8\cos^2\Theta_3 + ---- A^{4(n-1)}\cos^2\Theta_n)} \quad (26)$$

and the representative quadrature current is

$$I'' = I_o R_L \sqrt{(\sin^2\Theta_1 + A^4\sin^2\Theta_2 + A^8\sin^2\Theta_3 + ---- A^{4(n-1)}\sin^2\Theta_n)}. \quad (27)$$

By assuming that the representative in-phase and quadrature currents are equal the following steps can be greatly simplified. In view of the varying effects of frequency, distance from the sending end and nature of the irregularity upon the phase relations this appears to be a justifiable assumption, so combining I' and I'' in quadrature,

$$I' = I'' = \sqrt{\frac{I'^2 + I''^2}{2}} = \frac{I_o R_L}{\sqrt{2}} \sqrt{1 + A^4 + A^8 + ------- A^{4(n-1)}} \quad (28)$$

For a finite number of irregularities, that is a finite line terminated by a perfect network just beyond the nth coil:

$$I' = I'' = \frac{I_o R_L}{\sqrt{2}} \sqrt{\frac{1 - A^{4n}}{1 - A^4}} \quad (29)$$

which is obtained by summing up the series of terms under the radical in equation (28).

For an infinitely long line A^{4n} becomes zero since $A < 1$ and

$$I'_\infty = I''_\infty = \frac{I_o R_L}{\sqrt{2}} \sqrt{\frac{1}{1 - A^4}} \quad (30)$$

I' corresponds to the r.m.s. error in the ordinary theory of errors, consequently the

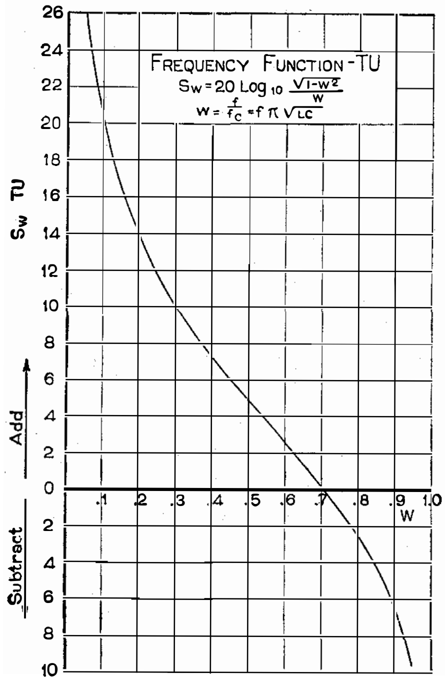


Figure 4

probability function for the distribution of the in-phase currents is:

$$p' = \frac{1}{I'\sqrt{2\pi}} e^{-\frac{i'^2}{2I'^2}} \quad (31)$$

Changing the accents, this equation also applies to the quadrature components.

The probability that the in-phase current lies between two near-by values i' and $i' + di'$ is then equal to $p'\, di'$ and the probability that the quadrature component also lies between two values i'' and $i'' + di''$ at the same time is

$p'di' \times p''di''$. Transferring to polar coordinates,[3] the probability that the total returned current will be between a value $i=\sqrt{i'^2+i''^2}$ and a slightly different value $i+di$ and also have a phase angle between Θ and $\Theta+d\Theta$ is

$$P=\frac{1}{2\pi I'^2} i e^{-\frac{i^2}{2I'^2}} di d\Theta \tag{32}$$

Integrating with respect to the phase angle Θ between O and 2π to find the probability of obtaining a current between i and $i+di$ of any possible phase displacement

$$F=\frac{1}{I'^2}\int_{I_F}^{\infty} i e^{-\frac{i^2}{2I'^2}} di. \tag{33}$$

Integrating between I_F and infinity gives the probability that the total returned current will exceed the value I_F.

$$F=e^{-\frac{I^2_F}{2I'^2}} \tag{34}$$

In a large number of lines, F is the fraction of the whole group which will have a return current in excess of I_F.

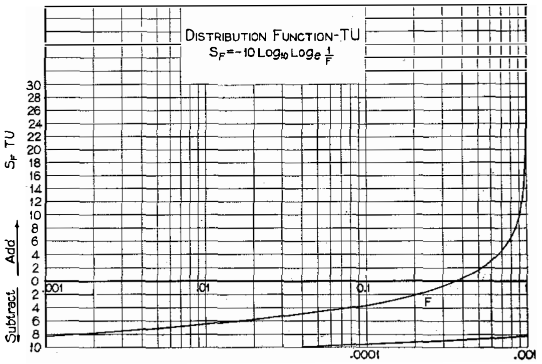


Figure 5

From the definition of the transmission unit the return loss of the line expressed in TU, is given by the expression

$$S=20 \log_{10}\frac{I_o}{I_F}=-20 \log_{10}\frac{I_F}{I_o} \tag{35}$$

from which

$$I_F^2=I_o^2 10^{-\frac{S}{10}}. \tag{36}$$

Substituting in (34)

$$F=e^{-\frac{I_o^2}{2I'^2}10^{-\frac{S}{10}}} \tag{37}$$

[3] For a more complete description of this operation, see "Advanced Calculus," by E. B. Wilson, page 390 et seq.

Taking logarithms to the base e and transposing

$$10^{-\frac{S}{10}}=-\frac{2I'^2}{I_o^2} \log_e F. \tag{38}$$

Taking logarithms to the base 10

$$S=10 \log_{10}\left[\frac{I_o^2}{2I'^2}\times\frac{1}{\log_e\frac{1}{F}}\right]. \tag{39}$$

Substituting the value of I'_∞ from equation (30) for I'

$$S=10 \log_{10}\left[\frac{1-A^4}{R_L^2}\times\frac{1}{\log_e\frac{1}{F}}\right] \tag{40}$$

ATTENUATION FUNCTION—TU
In terms of loss per loading section

$$S_A=10 \log_{10}\frac{1}{1-A^4},$$

A = Attenuation factor per loading section,

$L=20 \log_{10}\frac{1}{A}$ = loss per loading section in TU

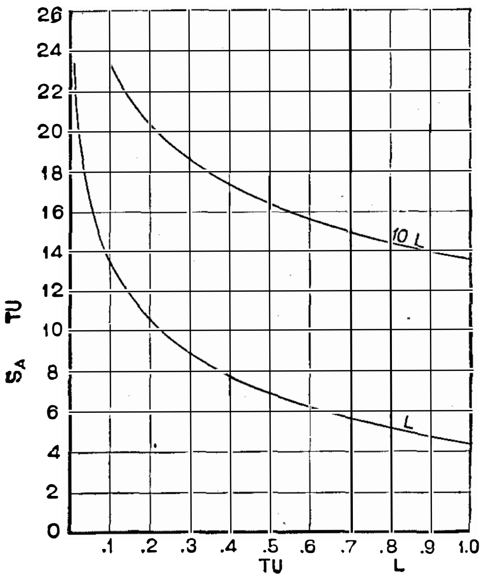


Figure 6

and the value of R_L from equation (25)

$$S=10 \log_{10}\left[\frac{1}{H_L^2}\times\frac{1-w^2}{w^2}\times(1-A^4)\times\frac{1}{\log_e\frac{1}{F}}\right]. \tag{41}$$

By a similar process of reasoning it is evident that if the line contains capacity deviations only, the return loss is given by this same expression of H_C substituted for H_L and if both types of irregularity occur the representative deviation is

$$H = \sqrt{H_L^2 + H_C^2}$$

when H_C includes the effect of spacing irregularities as well as capacity deviations in the cable. The foregoing expression can, for convenience, be put in the form

$$S = S_H + S_w + S_F - S_A \qquad (42)$$

in which each term depends upon only one independent variable and in which the symbols have the following meanings:

$$S_H = \text{Irregularity function} = 20 \log_{10} \frac{1}{H} \qquad (43)$$

$$S_w = \text{Frequency function} = 20 \log_{10} \frac{\sqrt{1-w^2}}{w} \qquad (44)$$

$$S_F = \text{Distribution function} = 10 \log_{10} \frac{1}{\log_e \frac{1}{F}} \qquad (45)$$

$$S_A = \text{Attenuation function} = 10 \log_{10} \frac{1}{1-A^4} \qquad (46)$$

Meaning of Equation (42)

To understand more clearly the meaning of the equation (42) imagine that a large number of circuits of the same type and gauge are to be built in accordance with the same specifications so that the representative (r.m.s.) deviation including all causes has the same value H for each circuit. Further, imagine that the value of S has been calculated by formula (42) using a particular frequency f and a convenient fraction F. It is to be expected that when the circuits have been built and their return losses measured at the given frequency f the fraction F of the whole group will have return losses lower than S and the rest will have higher return losses.

In discussing expected results it is sometimes preferable to state the fraction $1-F$ of the circuits whose return losses will be greater than the assigned value rather than the fraction F whose return losses will be lower. This is done in Figs. 9 to 14 described below.

Location of the First Irregularity

In equations (14), (15) and (16) and all the equations which depend upon them it was assumed that the first irregularity occurs at the sending end of the line. Two other assumptions are equally plausible and might under some circumstances be preferable. These are that the first irregularity occurs (a) at one-half section from the end or (b) at a full section. In the first case (a) the current returned to the sending end

Attenuation Function—TU

In terms of loss per mile of the circuit length of loading section 6000 ft.

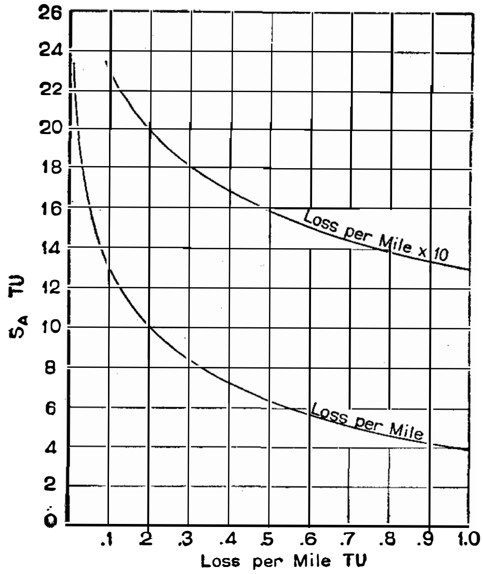


Figure 7

from each irregularity will be reduced by the factor A and in the second (b) by the factor A^2, that is the return loss given by equation (42) should be increased by (a) the amount of the transmission loss in one loading section or (b) twice the amount of the transmission loss in one loading section respectively.

Return Losses of Short Lines

When a line is short and regularly terminated the returned current will be somewhat less than if it extends to infinity with irregularities and consequently the return loss will be higher. From equations (29) and (30), the returned current is lowered in the ratio $\frac{I'}{I'_\infty} = \sqrt{1-A^{4n}}$ by limiting the line to n sections; consequently

$$S_n = S + (S_n - S) = S + 10 \log_{10} \frac{1}{1-A^{4n}} \qquad (47)$$

in which

$$S_n - S = 10 \log_{10} \frac{1}{1 - A^{4n}} \quad (48)$$

is the increase in return loss.

Since the transmission loss in n sections of the line is

$$T = 20 \log_{10} \frac{1}{A^n} \quad (49)$$

it is easily seen that the increase of return loss can be expressed as a function of this loss. Transposing (49) and substituting in (48)

$$S_n - S = 10 \log_{10} \frac{1}{1 - \left[\frac{1}{\log_{10}^{-1} \frac{T}{20}} \right]^4}. \quad (50)$$

Charts

The process of computing return losses can be greatly shortened by using the graphs of equations (43), (44), (45), (46), and (50) to obtain the values of the various functions. The accompanying Figures 3 to 8, inclusive, have been prepared to illustrate these graphs and for use in rough calculations.

Increase of the return loss when the line is limited to n sections

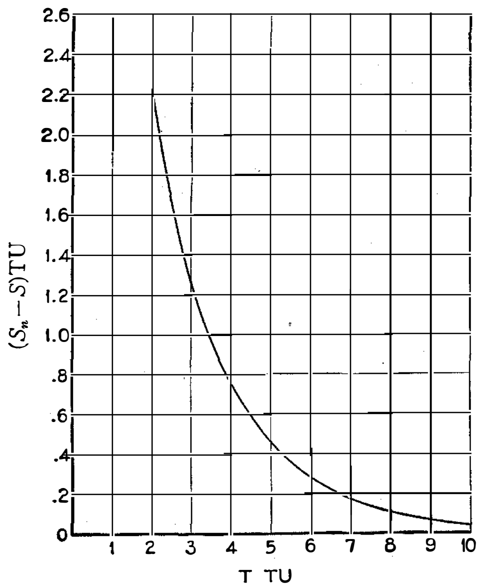


Figure 8

S_H may be obtained from any table or chart giving the relation between TU and current ratio by using H like a current ratio. Figure 3 is a chart drawn especially for this purpose. For values of H lying between 0.1 and 0.01 look up a point on the curve corresponding to $10H$ and add 20 TU to the corresponding value of S_H,

Return loss of No. 19-H-174-63 sides exceeded by various percentages of circuits at 500 cycles

Smooth curve—theoretical
⊙ 46-H-174-63 sides Pittsburgh to Ligonier
⊡ 12-H-174-63 sides Ligonier to Pittsburgh
△ 52-H-174-106 sides Pittsburgh to Ligonier

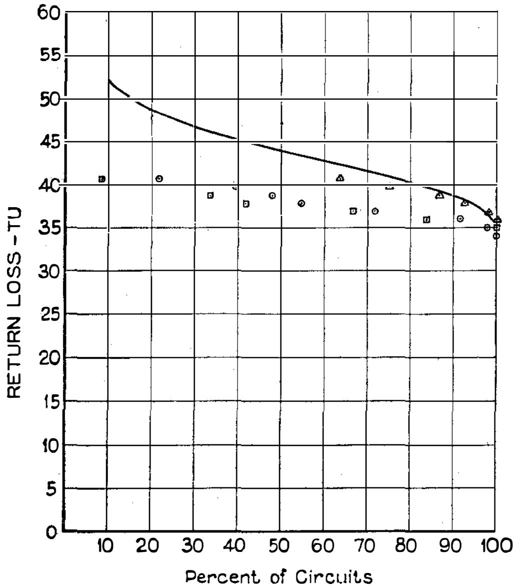


Figure 9

for values of H lying between 0.01 and 0.001 look up a point corresponding to $100H$ and add 40 TU to the value of S_H, and so forth.

Figures 4, 5, 6, and 7 are curves giving the relations between the functions S_w, S_F and S_A, respectively, and the quantities upon which each depends plotted from equations (44), (45) and (46). These are all positive except as indicated by the word "Subtract" on the diagrams.

A simple method for extending the curve of Figure 5 is as follows: (a) choose a point on the curve within 3 TU of the lower end, (b) subtract about 3 TU (accurately, $10 \log_{10} 2$) from the value of S_F for this point, and (c) square the value of F for this point. The results obtained for (b) and (c) are the coordinates of another point on the extension of the curve.

Figure 6 gives the relation between S_A and the transmission loss per loading section. On account of the wide use of 6,000 ft. spacing the curves of Figure 7 are plotted to give the relation between S_A and the transmission loss per mile for 6,000 ft. spacing which is usually a more convenient arrangement.

Figure 8 gives the amount, $S_n - S$, by which the return loss of a regularly terminated line of

Return loss of No. 19-H-174-63 sides exceeded by various percentages of circuits at 1000 Cycles

Smooth curve—theoretical

⊙ 46-H-174-63 sides Pittsburgh to Ligonier

⊡ 12-H-174-63 sides Ligonier to Pittsburgh

△ 52-H-174-106 sides Pittsburgh to Ligonier

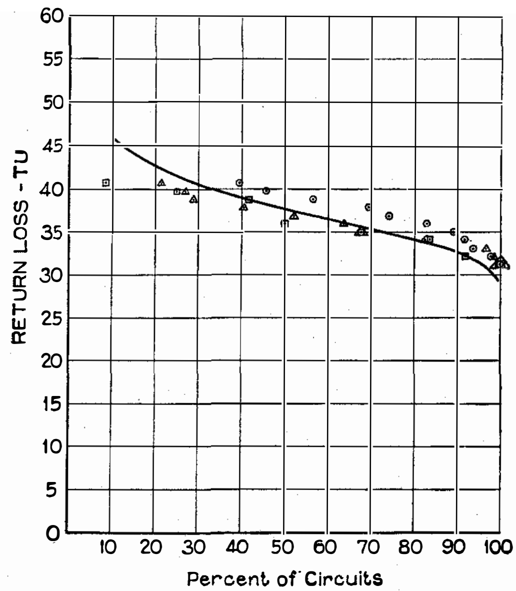


Figure 10

finite length (n section) is greater than that of an infinite line as a function of the transmission loss of the finite line. This was calculated by formula (50).

Calculation of Return Loss

The process of finding the return loss by means of the curves is as follows:

(1) Determine the value of H_L, the representative deviation of the loading coils, and H_C, the representative deviation of the capacity of the loading sections. These depend upon the variations allowed in the specifications for loading coils and cable and upon the care with which the line is built. Calculate $H = \sqrt{H_L^2 + H_C^2}$, the representative combined deviation of the section. Look up the number of TU corresponding to H in any suitable table or chart, such as Figure 3, to find S_H.

(2) Assume the frequency, f, to be considered. Calculate $w = \frac{f}{f_c}$ and look up the corresponding value of S_w on Figure 4.

(3) Assume a value of F and look up the corresponding value of S_F on Figure 5.

(4) Look up the value of S_A on Figure 7, corresponding to the transmission loss per mile of the circuit at the frequency f if the coils are spaced 6,000 feet (1.136 miles) apart, or calculate the loss per section and look up S_A on Figure 6, if some other spacing is used.

(5) Calculate $S = S_H + S_w + S_F - S_A$.

(6) If the return loss of a finite length of line is desired determine the transmission loss of this length and look up the corresponding value of $S_n - S$ on Figure 8. Add this amount to the value of S found in paragraph (5).

Example

As an example to illustrate the application of these methods let us calculate a return loss at 1,000 cycles for No. 19-H-174-63 [4] side circuits such that 90 per cent. of the circuits may be expected to have a higher value and only 10 per cent. to fall below it. The necessary data are given in Table II, below.

(1) $H = \sqrt{0.0062^2 + 0.0129^2 + 0.0045^2} = 0.0150$. Figure 3 gives 36.5 TU as the corresponding value of S_h.

(2) At 1,000 cycles $w = \frac{1000}{2810} = 0.356$.

Figure 4 gives 8.4 TU as the corresponding value of S_w.

(3) Since 90 per cent. of the finished lines are to have return losses greater than S and 10 per cent. less $F = 0.1$ and Figure 5 gives -3.7 TU as the corresponding value of S_F.

(4) The transmission loss per mile is 0.274. Since the coils are spaced 6,000 feet apart, Figure 7 gives 8.7 TU as the value of S_A. This same value would be obtained less directly by calculating the loss per loading section,

[4] This notation indicates a phantom group of No. 19 B. & S. conductors in a cable with loading coils spaced 6,000 feet apart, the side circuit coils having 174 millihenrys inductance and the phantom coils 63 millihenrys in accordance with the practices of the Bell System.

$0.274 \times \frac{6000}{5280} = 0.311$ and using Figure 6. The latter method is used when the spacing is different from 6,000 feet.

(5) Using equation (42)

$$S = S_H + S_w + S_F - S_A = 36.5 + 8.4 - 3.7 - 8.7 = 32.5 \text{ TU.}$$

This will be found to agree with the 90 per cent. point on the smooth curve plotted in Figure 10 which is described below.

(6) In case it is desired find the return loss of a length of this line having a transmission loss of, for example, 6 TU instead of the return loss of the infinite line. Figure 8 gives $S_n - S = 0.3$ from which

$$S_n = 32.5 + 0.3 = 32.8 \text{ TU.}$$

Return loss of No. 19-H-174-63 sides exceeded by various percentages of circuits at 2000 cycles

Smooth curve—theoretical
⊙ 46-H-174-63 sides Pittsburgh to Ligonier
⊡ 12-H-174-63 sides Ligonier to Pittsburgh
△ 52-H-174-106 sides Pittsburgh to Ligonier

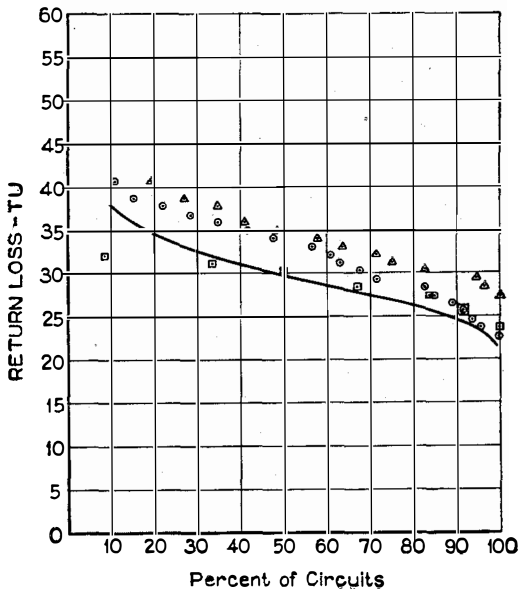


Figure 11

Determination of Tolerable Deviations

To determine the deviations which correspond to an assigned value of the return loss find values of S_w, S_F and S_A as in paragraphs (2), (3), and (4) above and substitute in formula (42) to find the value of S_H. This with a table or chart of TU and current ratio gives the value of H. Limits can then be imposed on the loading coil inductances and section capacities that will insure that the representative deviation will not exceed the value H so found.

Return loss of No. 19-H-174-63 phantoms exceeded by various percentages of circuits at 500 cycles

Smooth curve—theoretical
⊙ 25-H-174-63 phantoms Pittsburgh to Ligonier
⊡ 21-H-174-63 phantoms Ligonier to Pittsburgh

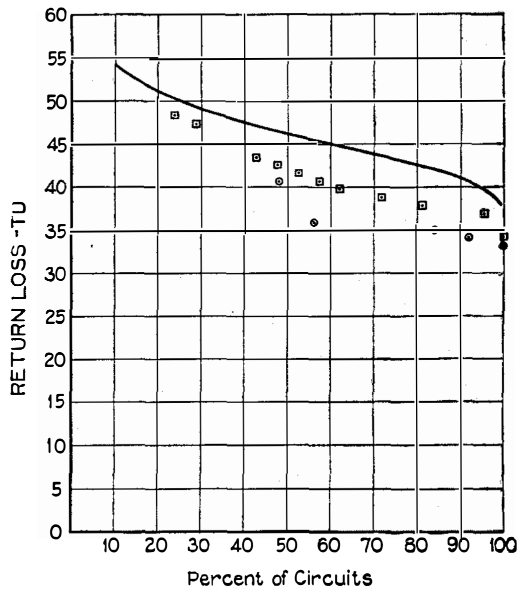


Figure 12

Comparison of Different Types of Circuits

These formulae are useful in comparing the return losses to be expected in various types of circuits which are built with the same accuracy in the matters of coil inductance and section capacity. In such cases it is merely necessary to calculate the quantity $S_w - S_A$ for each circuit and take the difference.

Example

As an example compare the No. 19-H-174-63 side circuits worked out above with No. 16-H-44-S[5] circuits at 1,000 cycles. Since the deviations and the fraction F are the same only S_w and S_A need be considered. For the No.

[5] This notation indicates a side circuit of No. 16 B. & S. conductors in a cable loaded with 44 millihenry coils spaced 6,000 feet apart.

16-gauge circuit $f_c=5560$ and the loss in TU per mile is 0.236. From these figures:

Gauge of Line	No. 19	No. 16
$w=\frac{1000}{f_c}$	0.356	0.18
S_w TU	8.4	14.8
S_A TU	8.7	9.4
S_w-S_A TU	-0.3	5.4

These figures show that the return loss of the No. 16-H-44-S circuits should be higher than that of the No. 19-H-174-63 side circuits and the difference to be expected is $5.4-(-0.3)=5.7$ TU.

When the circuits to be compared have the same cutoff frequency the process of comparison is even simpler since the quantity S_w is then the same in each case. S_A is determined for each circuit as in paragraph (4) above. The difference between the two values of S_A is the difference between the return losses.

Return loss of No. 19-H-174-63 phantoms exceeded by various percentages of circuits at 1000 cycles
Smooth curve—theoretical
⊙ 25-H-174-63 phantoms Pittsburgh to Ligonier
⊡ 21-H-174-63 phantoms Ligonier to Pittsburgh

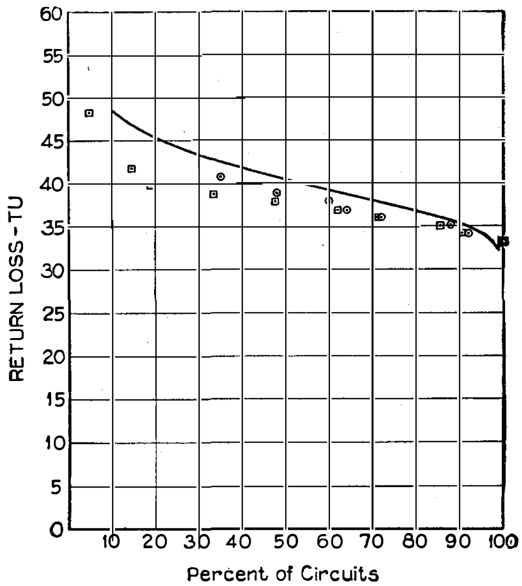


Figure 13

Example

As an example compare the No. 19-H-174-63 side circuits with No. 16-H-174-63 side circuits. In this case the cutoff frequencies are the same, so w and S_w are the same. It is then only necessary to compare S_A. The loss per mile of the No. 16-gauge circuit is 0.161 TU at 1,000 cycles from which $S_A=11$ TU. In equation (42) S_A is negative hence the No. 19-gauge will have a higher return loss than the No. 16-gauge circuits and the expected difference is $11-8.7=2.3$ TU.

Comparison of Calculated and Measured Return Losses

In order to test the methods of calculation described above a series of measurements of return loss at 500, 1000 and 2000 cycles were made on a group of loaded side and phantom circuits in a cable using a No. 2-A unbalance measuring set.

Return loss of No. 19-H-174-63 phantoms exceeded by various percentages of circuits at 2000 cycles
Smooth curve—theoretical
⊙ 25-H-174-63 phantoms Pittsburgh to Ligonier
⊡ 21-H-174-63 phantoms Ligonier to Pittsburgh

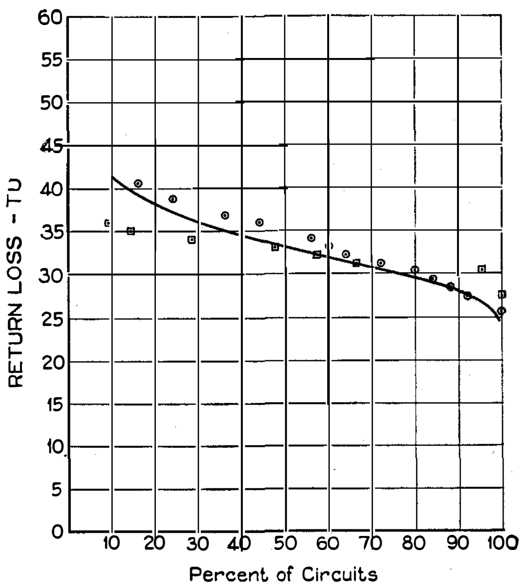


Figure 14

The representative inductance deviations were found by analyzing the inductance measurements on a large group of loading coils similar to those used in the cable. The representative capacity deviations, not including the spacing irregularity were found by analyzing the shop measurements on a number of reels of the cable. This gave representative figures for reel lengths which were divided by $\sqrt{12}$ (in accordance with the laws of probability since this cable had 12 reels lengths in a loading section) to obtain the representative capacity deviations due to the cable for the loading sections. The spacing deviations were separately determined from the measured distances between the loading points.

The data used in the calculation were as follows:

TABLE II

		Sides	Phantoms
Representative inductance deviation		0.0062*	0.0061*
Representative capacity deviation		0.0129*	0.0138*
Representative spacing deviation		0.0045*	0.0045*
Combined representative deviation, H		0.0150*	0.0158*
Cutoff frequency f_c (cycles per sec.)		2810	3727
Transmission loss TU per mile	500 cycles	0.265	0.271
	1000 cycles	0.274	0.279
	2000 cycles	0.317	0.296

The smooth curves of Figures 9 to 14, inclusive, were calculated from the data in Table II using the methods described above. The abscissas are the percentages of a large group of circuits which may be expected to have return losses greater than the values given by the ordinates. This percentage is equal to 100 $(1-F)$. The points plotted on the curve sheets give the measured values of return loss found in the groups of circuits listed in the explanatory notes on the drawings.

In general, it will be observed that there is a fair agreement between the theoretical curves and the measured return losses especially at 1000 and 2000 cycles.

* The figures are "fractional" deviations. Percentage deviations which are sometimes used are 100 times as large. Care should be taken to avoid errors caused by failure to divide percentage deviations by 100 before finding the value of F_H.

Due to the limited range of the measuring apparatus, readings of return losses greater than 40.7 TU were not made except in the case of the Ligonier to Pittsburgh phantoms shown on Figures 12, 13 and 14, when a special arrangement was available to extend the range to 47.3 TU. For this reason points representing observed return losses above these limits are not available which causes the observed values for 500 cycles in Figures 9 and 12 to appear somewhat low at first sight.

Where the highest point in a given set of data represents many circuits as in the cases represented by the small triangles and circles in Figure 9 this point probably gives closely the return loss corresponding to the percentage of circuits it indicates but the points for higher return losses are not available. When the highest point represents only one or two circuits as in the case represented by the square in Figure 9, it is likely that the actual return loss is higher than the point indicates.

It should also be noted that above 40 TU the actual impedance of the line and its characteristic impedance differ by less than 2 per cent. so that very small departures of the network from the true characteristic impedance of the line would tend to make the observed return loss low.

Conclusion

It is believed that the procedure described in this paper offers a reliable method for determining the probability of attaining a particular value of return loss at any assigned frequency when a circuit is built with definite limitations on inductance and capacity deviations so that the representative deviations are known.

General Engineering Problems of the Bell System

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NOTE: This paper, read before the Bell System Educational Conference, Chicago, June 22-27, 1925, discusses the character and scope of the important problems involved in caring for the growth and operation of the Bell System. The plant extensions necessary to meet service requirements and the necessity of advanced planning are first taken up. The uses of the "Commercial Survey," the "Fundamental Plan" and engineering cost studies are analyzed to illustrate how an engineer attacks the problem of furnishing satisfactory telephone service to the public. A discussion of the New York-Chicago toll cable and the telephone problem in New York City, as illustrative of specific engineering problems, concludes the paper.

THE problem of giving telephone service is quite different from that of most business enterprises. The merchant, for example, may take more business in his store without necessarily always increasing his facilities. The minute we take another subscriber, however, we add to our plant and plant investment. Similarly, in connection with the manufacturing industry, the manufacturer, for instance, is in a position to exercise very direct control over his activities. In the telephone industry, however, our obligation is to take the service as requested and be prepared to deliver it when and as it is required. Furthermore, the activities of the telephone business are of such a nature as to make it essential, regardless of the remoteness of the territory or of the physical and climatic conditions involved, that a way be found, as far as practicable, to construct and maintain the plant and safeguard the service to the public.

To meet these exacting requirements calls for the greatest ingenuity and foresight in the design of the telephone plant and involves careful study of various plans for plant extension and rearrangement with a view to the selection of the most economical and desirable plan. Having determined the fundamentals of design, there must, of course be devised ways and means of safely constructing and efficiently maintaining the plant. Furthermore, as the plant is necessarily scattered over a very large territory and as the different parts must work together satisfactorily and with the most economical results, a high degree of standardization is required, still leaving, however, freedom to adapt the plant to different local conditions. We find evidence on every hand of the value of this standardization, not only during normal conditions, but also during emergencies, when it has been possible to quickly assemble equipment or materials from any part of the system and promptly restore or expand the service as required.

Important engineering problems of great variety, therefore, present themselves on every hand calling for consideration by the engineers in the General Engineering Departments, as well as the Traffic, Plant and Commercial engineers associated with the operating divisions of the companies.

PLANT EXTENSIONS TO MEET SERVICE REQUIREMENTS

A very large part of the engineering work of the Bell System is concerned with the design of plant extensions to meet expected future service requirements with the maximum economy consistent with maintaining the service standards of the system. I shall not discuss the magnitude of the various activities and requirements of the system, but will recall to your mind a few of the outstanding items to better illustrate the magnitude of this part of the engineering work.

Telephone stations are being connected at the rate of over two and one-quarter million annually.

The resulting net additions or gain in stations per year is approximately 800,000.

To meet this station gain and to replace equipment removed from plant, switchboards are being added at the rate of approximately 1,200,000 station capacity annually.

The Bell System installs in one year approximately 30 billion feet of insulated conductor in lead covered cable ranging in unit sizes from 1 pair to 1,212 pairs. Of this amount, more than 27 billion conductor feet constitute the net annual increase in conductor mileage.

The above plant additions, together with other important items, such as poles, wire, etc., involve a net increase in the telephone plant of nearly three hundred million dollars annually.

It is of interest to note, in this connection, that the annual additions to the telephone plant today are equivalent to the entire plant in service in the Bell System as of about 20 to 25 years ago.

Necessity for Advance Planning

Obviously with a program of this magnitude and of such diversity in the character of its related units, careful advance planning is necessary to insure economical and satisfactory performance.

In the earliest days of the telephone service, the problem of laying out a telephone plant was a simple one. A very small switchboard, simple in character and easily moved, if necessary, was placed in some convenient location, usually in rented quarters, and from that switchboard wires were run one by one as needed, to the premises of those desiring service, either on poles or over house-tops. Under such simple and rudimentary conditions, no serious question of the future needed to be answered. Today, how different is the telephone situation in many large cities, such as Chicago, or throughout the system. Large and specially designed buildings must be constructed for the accommodation of the necessary interconnecting or switching mechanisms; expensive switchboards must be placed in these buildings; conduits must be extended from each of these buildings along appropriate routes to reach the thousands of telephones which receive service from these switchboards; other conduits must be placed between these switchboards and the other buildings and switchboards throughout the city so as to provide the means of intercommunication between the subscribers connected with the switchboards located in different buildings; still other conduits and cables must be placed between these switchboards and the central switchboard or toll board from which radiate cables and conduits and lines extending to the suburban area, to adjacent cities, to all the other principal cities in the United States, and to Canada.

Each of the buildings must be placed in some definite location and it is necessary to plan this well in advance and to direct the growth of the plant toward that location, even though the building may not be built for some years hence. Otherwise, very serious and costly rearrangements of plant would be necessary at the time the office is opened. Furthermore, each building must be planned for some definite ultimate size, although, of course, the whole building need not be built at one time. Ducts cannot be placed under the streets one by one as needed. Public sentiment would not, of course, tolerate the opening of important street routes several times, or even once, each year for the purpose of placing an additional duct. Neither would it be economical, if practicable, to construct conduits in this piecemeal way. The manholes in these conduits must be planned with reference to the number of ducts extending into them, not only the ducts initially placed, but if side runs are to be made from these manholes or if other ducts are to be placed later, this fact must be foreseen and provided for, or extensive and expensive alterations are inevitable at a later date.

I might go on and multiply the conditions which must be met in constructing telephone plant in a country such as ours in which not only the population is growing and moving, but where the demand for telephone service is growing more rapidly than the population. We are in effect planning a growing organism and we must recognize that we are dealing with ultimate tendencies largely beyond control, the effects of which are not capable of exact valuation. However, enough has been said, I believe, to indicate clearly to you that the telephone company on every item of its buildings, conduits and cable construction must constantly answer for itself vital questions as to the future requirements of the system.

This was early recognized, and one of the most important engineering problems of the Bell System has been the formulation of estimates of expected future telephone business both as to quantity and expected location, and the development, from these estimates, of basic plans of procedure, which plans must, of course, be flexible, capable of modification from time to time, and such modifications must be made as changing conditions show them to be advisable.

Our first step in determining the estimated future telephone requirements is to prepare a so-called "Commercial Survey" of the city, covering the requirements fifteen or twenty years ahead. These studies include a critical analysis of the existing market for telephone service, pertinent facts as to the present sale of telephone service, of classes of service and users and forecasts of the market for telephone service at the future date or dates. Consideration is also given to the growth and distribution of population, expected changes in general wage levels, etc., and assumptions of the amount of business that must be sold in each area on the future dates selected under assumed rate conditions.

Having thus determined from the "Commercial Survey" the requirements for telephone service for various parts of the city at the future date assumed, it is next essential to develop a comprehensive plan to serve as a basis for the layout of the plant to meet these requirements. Accordingly, a so-called "Fundamental Plan" is made for the community covering these conditions as estimated fifteen or twenty years hence. The importance of such a plan is obvious, but a brief reference to some of its features will, I believe, be of interest.

In laying out a plan for a city, the engineer might, as an extreme case, center all the subscribers' lines at one building. Obviously, we would have a maximum efficiency in operation in some respects, in that we had grouped all of our switchboards together, but our outside plant costs would be at a maximum and other disadvantages would be experienced. As the other extreme, the engineer might place many small buildings around the city, thus placing the outside plant costs at a minimum, but increasing the difficulty and expense of operating so many centers. Obviously, therefore, there is some arrangement between the two extremes I have cited which would provide the most economical and satisfactory layout of the plant. Several test cases, which in the judgment of the engineer seem promising, are, therefore, studied and the most economical and satisfactory plan determined upon. In completed form, these "Fundamental Plans" furnish us the following essential information upon which to proceed with the more detailed studies covering plant extensions.

a. The number of central office districts which will be required to provide the telephone service most economically and the boundaries of these central office districts.

b. The number of subscribers' lines to be served by each central office district.

c. The proper location for the central office in each district to enable the service to be given most economically with regard to cost of cable plant, land, buildings and other factors.

d. The proper streets and alleys in which to build underground conduit in order to result in a comprehensive, consistent and economical distributing system reaching every city block to be served by underground cable.

e. The most economical number of ducts to provide in each conduit run as it is built.

Our experience has shown that these fundamental plans reduce guesswork to a minimum by utilizing the experience of years in studying questions of telephone growth in order to make careful forecasts on the best possible engineering basis. These fundamental plans, together with related studies, thus provide a general program of plant extension to be followed throughout the period for each of our cities and somewhat similar plans are, of course, undertaken for determining the future requirements of our intercity or toll facilities.

It is evident that both the ultimate arrangement and the program whereby it is to be obtained must have the utmost flexibility in order to meet unforeseen requirements, must work in satisfactorily with the existing plant, which represents an investment of over $2,500,000,000 must meet immediate service requirements, and also permit full advantage being taken of new developments in the telephone art.

The specific or detailed plan for each project of plant extension, whether within the cities as discussed or between cities in the toll line plant must, of course, be started early enough so that adequate time is allowed for completion of the construction work before the new facilities are required. The complete interval between starting work on such a project and getting it into service can seldom be less than one year and in the case of building and central office equipments must, of course, be longer.

Engineering Cost Studies

Owing to the complexity of the problem of suitable advance planning for the growth in the telephone plant as already discussed, it is evident that in the study of plans for specific projects, selection must generally be made between a choice of arrangements, more than one of which might satisfactorily meet the requirements of the service. It is usually necessary, therefore, that two or more practical plans or programs for construction must be compared so that the most advantageous plan may be selected. An important factor in the selection of all of these cases is a study of the relative economies of the different plans; that is to say, a comparative cost study and as these studies form such an important part of our engineering work, I believe it will be of interest to devote a few moments to a description of the important considerations generally involved.

These engineering cost studies require analysis and consideration of the cost and resulting annual charges for different amounts and types of plant included under each plan. The annual charges comprise items of expense incident to ownership of plant and those that are incurred each year after its installation to keep it in operation and in serviceable condition. As a general thing, in these cost comparisons, another interesting factor is also present; namely, most of the plans which are compared call for expenditures to be made at different periods. For example, one plan might call for erecting a new building at a new location immediately; whereas under the other plan being considered, the necessary additional space required could be secured by adding to an existing building and deferring the complete new project for possibly five or ten years. The relative economy of the plans, therefore, cannot be determined directly by a detailed comparison of the expenditures involved or resulting annual charges, but it is necessary in order to give a fair comparison to express the relative costs of the different plans in terms of present worths, or equivalent annuities which give figures for the total expense in which accurate allowance is made for the variation of expenditures with respect to time.

These engineering cost comparisons may be considered as composed of four parts or operations; namely, the premises or known factors and assumptions; the formulation or set-up of the problem; the solution or mathematical calculations and finally the interpretation of the results. The determination of the premises and formulation of a given problem is, of course, a matter specific to that problem, and here the engineer must exercise sound judgment, for unless the assumptions upon which the work is based are reliable the study itself is of little value. The mathematical calculations are, of course, a definite thing. However, the interpretation of the results must always be a matter of engineering judgment and full weight must be given to those factors which by their nature cannot be evaluated in the cost comparison.

A cost study is a fundamentally important tool in assisting the engineer to reach a decision as to the most desirable plan or program, but as indicated it cannot be used to replace the exercise of judgment on his part. The solution of an engineering problem is, in general, not a matter that can be demonstrated mathematically as can, for example, the proposition, that the square of the hypotenuse of a right triangle is equal to the sum of the square of the two sides. An engineering study rather requires in addition to all of the definite facts that can be brought to bear on the question the exercise of sound judgment on the part of the engineer in weighing the results of the cost study with all related business or other factors bearing on the problem.

Some factors involved in these engineering studies are often of a character which do not permit of expression as a direct charge against a given plan, but must be considered on a broader basis such as the difference in quality or dependability of the service, etc. Also it is important to keep in mind, for example, that, other things being equal, a plan requiring large investments has disadvantages as compared with one requiring a smaller investment so that even though the plan involving a larger investment may prove in from the cost study by a small margin, it may be desirable to adopt the alternative plan so as to avoid tying up considerable amounts of fixed capital. Another question to be kept in mind in interpreting cost studies is whether the more expensive type of plant, usually a higher type of plant, can be adopted satisfactorily at a later date or whether the decision to be made at the present time precludes its adoption later. In the former case it is often wise to go further in deferring fixed capital expenditures than in the latter case. Finally, throughout all of his work the engineer must have foremost in his mind the fact that the telephone system exists for the purpose of furnishing service to the public and the results of his engineering effort should insure a service which is satisfactory from the subscriber's viewpoint.

It is evident from what has been said, I believe, that these engineering cost studies are of great benefit in working out the proper procedure in our engineering work, and I assume they are equally helpful in the engineering of any kind of growing plant. Anything that can reasonably be done, therefore, to give the student an appreciation of the nature, scope, and application of the economic considerations of these engineering problems and to develop his faculties of judgment, imagination, team play, and other related qualities, will doubtless prove of great value to the student in his later engineering work.

Other Phases of Engineering Work

I have thus far described to you some of the very important engineering problems involved in the planning and carrying out of plant extensions to meet expected future service requirements. I would like next to consider with you a few of the engineering problems that present themselves in the actual design or operation of these large extensions to plant as introduced.

The rapid development of the telephone system, including the tremendous growth in the number of telephones in service and the rapid increase in the extent of territory which can be reached from any telephone, has led to a great increase in the importance and difficulty of the technical problems involved in the design and maintenance of the plant.

These technical problems cover a very wide range. The electrical and acoustic problems involved in the transmission of speech have led telephone men to much pioneering work dealing with the flow of sustained and transient alternating currents in electric circuits of all types and in the fundamental nature of speech and hearing itself. Again, the economical design of outside plant with suitable strength and economy involves investigations of characteristics of construction and materials and the preservation of timber, and there are, of course, special mathematical and other problems involved in the design of long cable or wire spans. Buildings and associated central office equipments involve very interesting mechanical and electrical problems in the matter of the layout of the buildings and the arrangement of apparatus to meet exacting requirements. These include many problems in the design of means for automatically supervising the progress of telephone connections and in the design of thousands of types of apparatus to meet specific mechanical and electrical requirements.

What I have already said emphasizes the importance of engineering work involved in the design of new plant. Very interesting engineering studies are, however, also involved in connection with the maintenance of the plant as well. This includes the development of improved maintenance methods and routines and a critical analysis of the results obtained, judged from the points of view of excellency of the service and economy of operation. To use a homely illustration: one might have his automobile completely gone over by a garage every 100 or 200 miles of running with the result that he would probably be reasonably sure of perfect maintenance of the automobile (assuming a perfect garage), but the maintenance costs would be excessively high and out of proportion to the benefit received. On the other hand, however, if no attention is given to the maintenance of the automobile, maintenance costs would be at a minimum but the depreciation would be high, the operation would soon become unsatisfactory and sooner or later the results would be a total interruption to service use. The problem, therefore, evidently is to find the proper balance between overall costs and service results, and this is true, of course, of the various engineering problems to be solved in connection with the maintenance of the telephone plant.

The engineering work of the Bell System also involves, to a large extent, relations with other organizations. These relations are very close with other wire-using companies, including small telephone companies whose lines connect with those of the Bell System. Important relations must be maintained by the engineer with electric power and electric railway companies, as particularly important problems of safety and of service arise due to the proximity between their electric circuits and the telephone circuits. These problems involve provision not only for the pro-

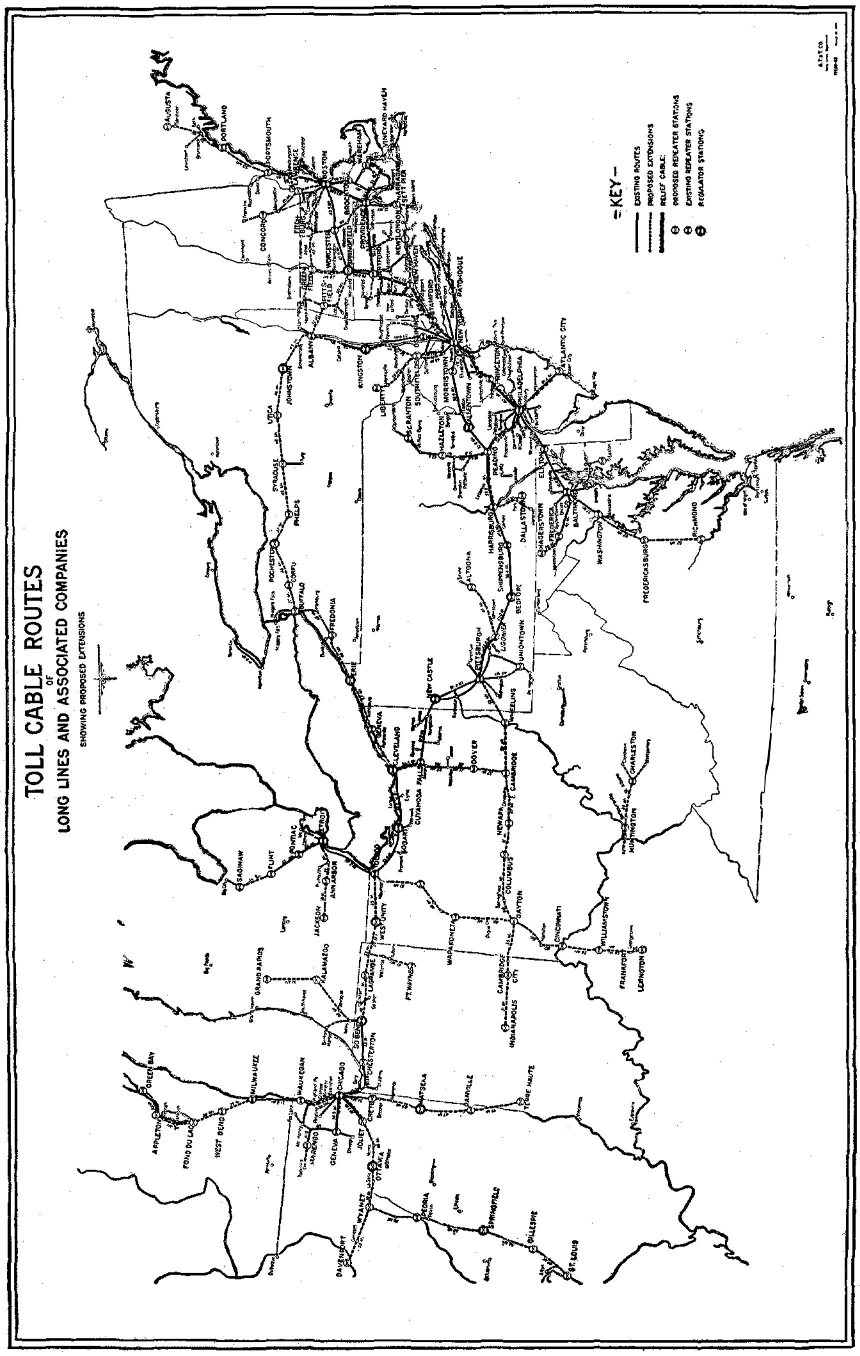
TOLL CABLE ROUTES
OF
LONG LINES AND ASSOCIATED COMPANIES
SHOWING PROPOSED EXTENSIONS
—KEY—
EXISTING ROUTES
PROPOSED EXTENSIONS
RELIEF CABLE
PROPOSED REPEATER STATIONS
EXISTING REPEATER STATIONS
REGULATOR STATIONS

Figure 1

tection of the plant and employees against the danger of contact with the wires of other companies but also include coordination of the two systems to prevent excessive inductive effects which often become important where electric power lines or electric railways and telephone lines run parallel to each other. The electric companies and the telephone companies often find it advantageous to enter into arrangements for the joint use of pole lines and this presents many problems requiring consideration by the engineer. It is evident, therefore, that the problems of the telephone engineer cover a very wide and interesting field in mechanical, electrical and other arts, both within the business itself and in relation with other utilities and municipal, state or national bodies or associations.

Specific Projects Illustrating Telephone Engineering Problems

Enough has been said, I believe, in the foregoing to indicate the general nature of the engineering problems handled in the Bell System. It is, of course, impracticable and doubtless would be tiresome in a talk of this character to deal specifically with many detailed engineering problems involved in the work which I have just described in general terms. I believe that you will gather a better appreciation of what some of these problems are from the inspection trips which form an important part of this week's program, than you could by a full discussion of them here. It will probably be of interest, however, before closing to outline briefly one or two typical telephone engineering problems of considerable magnitude.

New York-Chicago Toll Cable

The first large engineering problem I will consider is that relating to the New York-Chicago toll cable as shown in Fig. 1. This cable follows a route from New York through Harrisburg, Pittsburg, Newcastle, Cleveland, and thence to Toledo, and when completed will extend to South Bend and then on to Chicago. For parts of the distance through the congested sections it is underground, and through the open country it is aerial.

Until a comparatively few years ago practically all long toll circuits were in open wire construction; that is, individual wires mounted on separate insulators attached to cross-arms on poles. This was a natural development at first, due to the small number of circuits usually involved, but was also necessary because of the relatively high transmission losses of cable circuits where, as you know, the wires are insulated by wrapping paper, closely twisted together in pairs and quads, and large numbers of these compressed together within a lead sheath. The

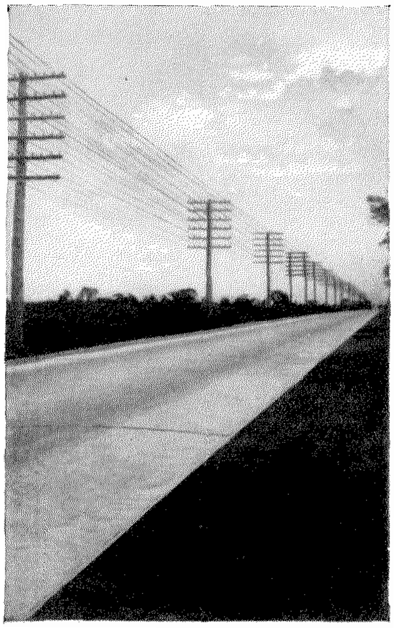

Figure 2—Open wire toll line

rapidly increasing use of toll service, however, pointed to difficulties in providing for future growth with open wire lines. In different parts of the route between Chicago and New York, for example, there were three and four heavily loaded open wire toll lines and the rate of growth was so rapid it was evident that before long difficulty would be experienced in obtaining suitable routes for the additional pole lines required.

Early efforts were accordingly made to devise means which would permit of satisfactory talks through cable and as a result of very intensive research there were developed satisfactory forms of telephone repeaters; that is, devices for amplifying feeble telephone currents, passing in either direction over a telephone circuit, without appreciable distortion. The most successful repeaters of this type, as you may know, use as the amplifying element the vacuum tube, although the tube itself is but a very small part of the apparatus required for the successful operation of the telephone repeater, and many interesting engineering problems had to be solved in providing a complete repeater. A full discussion

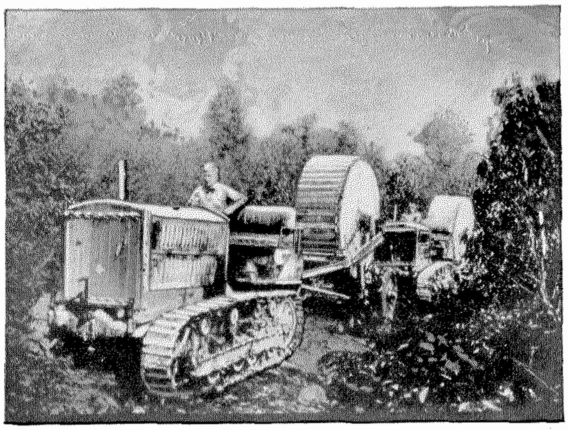

Figure 3—Transporting cable reels through Allegheny Mountains

of this very important and interesting development is given in a paper by Mr. Gherardi and Dr. Jewett, published in the Transactions of the A. I. E. E. for 1919.

The toll cable development, based on the use of repeaters as outlined above and many other technical improvements, now makes it possible to give satisfactory service between Chicago and New York and intermediate points over toll cable circuits of such small gauge that close to 300 circuits can be included in a single sheath of $2\frac{5}{8}''$ in diameter. The same number of circuits would require four or five very heavily built pole lines of open wire construction such as is shown in Fig. 2.

The construction of the Chicago-New York cable was started in 1918 and will be completed this year. As shown in Fig. 1, the cable is now in service between Chicago and South Bend, Indiana, and between New York and points as far west as Toledo. This cable is one element of a very extensive network of toll cables, particularly in the northeastern part of the country. Important cables in service or being installed out of Chicago, in addition to the New York-Chicago cable, include cables from Chicago to St. Louis, Chicago to Terre Haute, Chicago to Milwaukee, Chicago to Davenport, Iowa. During this year the Bell System is installing over 1,000 miles of toll cable containing more than 2 billion 500 million feet of insulated conductor.

The successful operation of long circuits of this cable network has been brought about only by the solution of very difficult technical problems, some of which have already been mentioned. It may be of interest to state that the long through circuits in this cable will be in the nature of four-wire circuits; in other words, one pair of small gauge wires with repeaters will be used for talking in one direction and a similar pair so equipped will be used for talking in the other direction. As an illustration of another type of problem involved, it may be of interest to mention that it is necessary to employ automatic regulators which vary with changes in the temperature of the cable conductors, the amplification introduced into the circuit by some of the repeaters. Without regulation, the change in temperature occurring within 24 hours often makes as much as a thousandfold difference in the amount of electrical energy received over New York-Chicago circuit from the same in-

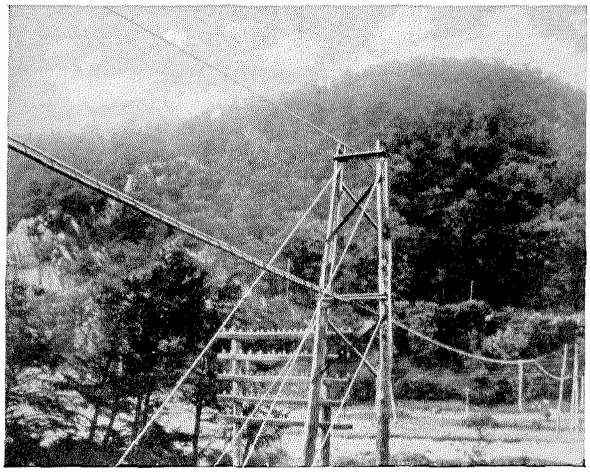

Figure 4—Toll cable line in Allegheny Mountains

put, a variation which would, of course, utterly prevent giving service over the circuits.

Aside from the electrical difficulties there were also interesting problems of a mechanical engineering nature to overcome in the design and placing of the cable, particularly where it passes through the wilderness of the Allegheny Mountains as shown in Figs. 3 and 4. The cable is for most of its distance strung on pole lines and these lines were designed especially to withstand the stresses caused during sleet storms. The decision as to whether the cable should be underground or aerial in the various sections in itself involved many engineering considerations.

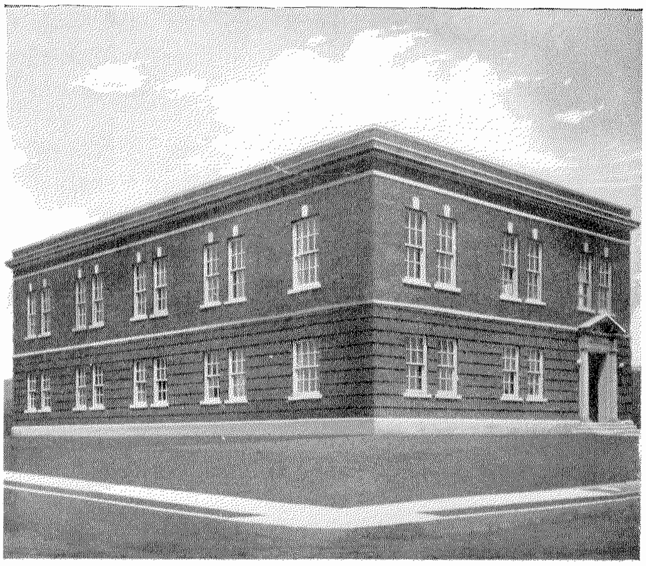

Figure 5—Typical telephone repeater station

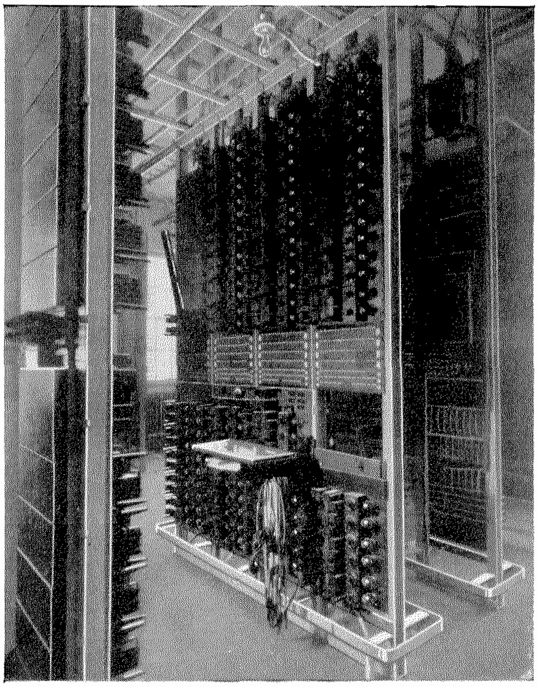

Figure 6—Bank of 2-wire telephone repeaters

In addition to the engineering matters in connection with the cable itself, other interesting problems present themselves, of course, with regard to the design and construction of the telephone repeater stations and their associated equipment, the telephone repeaters being inserted in circuits of this character at intervals of about 50 miles. A typical repeater station is shown in Fig. 5, a bank of two-wire repeaters in Fig. 6, and a bank of four-wire repeaters in Fig. 7.

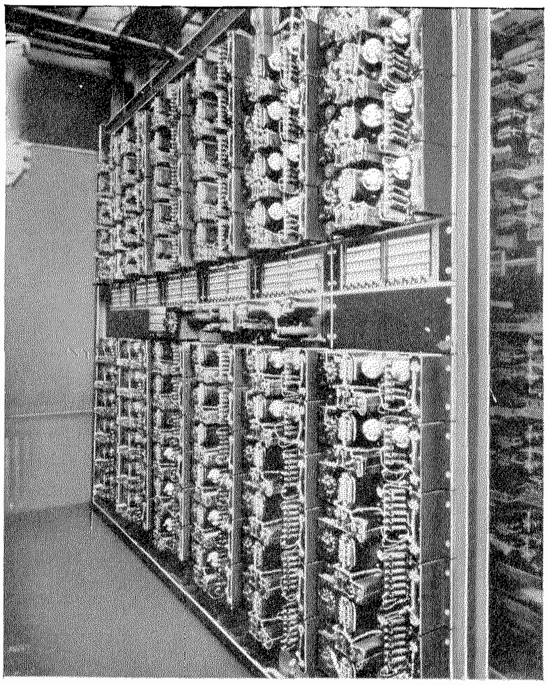

Figure 7—Bank of 4-wire telephone repeaters

Fig. 8—Toll cable line showing loading coil case

Fig. 8 shows a view of the completed cable. In this case a loading coil case is also shown, and the picture indicates again the physical problem of erecting a cable through the less accessible sections of the territory. Fig. 9 shows another

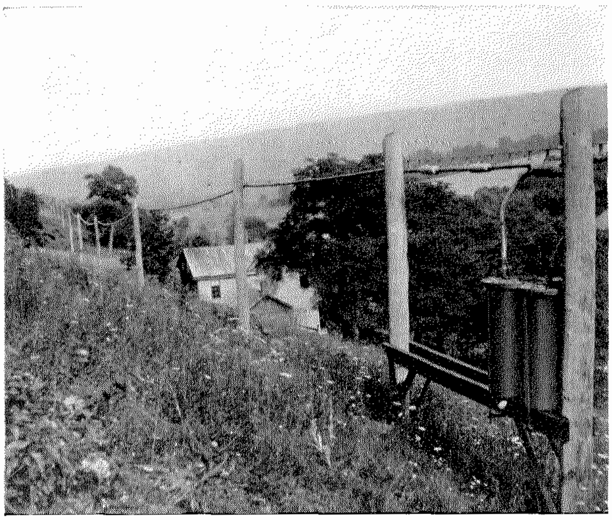

Figure 9—Toll cable line through open country

section of the completed cable through open country, and shows loading coil construction and facilities for cutting in additional loading coils as required. Fig. 10 gives an interesting view of the cable over the Alleghenies, showing us again the mechanical problems involved in design and construction. In this case the cable follows closely the open wire line, which in time will be dismantled.

It may be of interest in this connection to state that plans to be compared in the study of toll cable projects generally differ primarily in the dates at which they contemplate supplementing or replacing open wire service by cable. Conditions under which cable becomes economical depends, of course, on many factors. Perhaps the most important single factor is the rate of growth of the circuit requirements. The detailed design of the cable also involves very interesting studies of the economical number of circuits to provide in the cable sheath. Also the economical gauge of each circuit must be considered, comparing in many cases the economies of a larger gauge with those of a smaller gauge provided with a greater number of telephone repeaters.

The design of the toll cable as discussed is but one illustration of the design of the toll plant extension as a whole, a problem which, in general, involves the consideration of the relative desirability of additions to existing open wire toll lines, building new open wire toll lines, applying carrier telephone systems to existing lines or installing toll cable.

Telephone Problem in New York City

As another specific illustration of the telephone engineering problem, I will describe briefly the matter of adequately meeting requirements in a large city, using for purposes of illustration the situation in New York City and the metropolitan area. This particular situation doubtless presents one of the most difficult engineering problems and in some respects is unusual, yet, on the

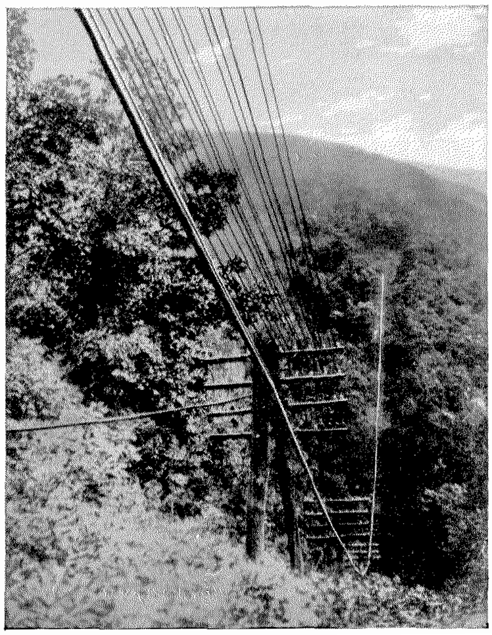

Figure 10—Cable and open wire toll line in Allegheny Mountains

other hand, it fairly represents the kind of engineering problem with which the Bell System engineers must deal at all times.

Fig. 11 indicates clearly the magnitude of the present and future problem in the New York metropolitan area, as viewed from the number of telephones. In 1905 there were 220,000 stations in New York City and 300,000 stations in the metropolitan area. By 1925 the figures had increased to 1,400,000 for New York City and 1,900,000 for the entire area. By 1945 it is estimated there will be over 3,000,000 stations in New York City and over 4,000,000 in the metropolitan area. Part of this growth can be ascribed to the normal increase in the population and part,

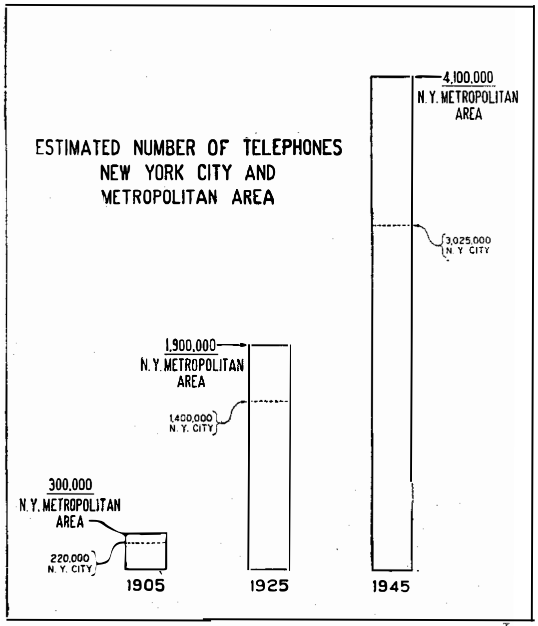

Figure 11

of course, to the tendency to make more use of the telephone. In addition, part of the growth is due to the conditions following the World War and the general economic trend.

Comparing 1924 with 1914, wholesale commodity prices, as you know, have risen over 50 per cent; the cost of living over 60 per cent; wages in manufacturing industries over 100 per cent, while in the same period telephone rates generally have increased less than 30 per cent, and even less than this in some of the larger cities. Telephone service, therefore, represents a large value for its price and in a situation like Greater New York, where there are between seven and eight million people, it is but natural that the new situation in the economic balance of things, together with the low price of service shown, would make for a very substantial increase in the demand for telephone service. This has, of course, also been true elsewhere.

As I have shown there are at present a total of over one million telephone stations within New York City proper served from about 130 central offices, 26 offices having been added last year. The predictions are that within the next twenty years the stations and central offices will have more than doubled. Each subscriber in this great network must be able to reach promtly every other subscriber. Due to the large area involved, a great number of calls within the city necessitates extra charges, which means that they must be specially supervised and recorded. There are many different classes of service furnished the public, such as measured rate, flat rate, coinbox, etc., and, of course, such other special services as Information service. Not only individual lines but party lines and private exchanges must be cared for. Furthermore, the demands for service to the extensive area surrounding this great city, as well as the large number of cities, towns and rural communities throughout the entire country, require that provision be made for thousands of toll messages daily. The problem of giving satisfactory service under these conditions and under the complications that come with the tremendous growth referred to is a very important one and requires careful and constant study.

In order to properly care for this complex problem of furnishing telephone service in large cities, telephone engineers in line with the efforts which have been made from the time of the early switchboards have endeavored to perform the various operations automatically so far as consistent with service requirements. While the switchboards which you saw yesterday are called "manual" switchboards, you doubtless noted from the demonstration and your visit through the central office that many of the operating features are automatic in character. The latest step in this general trend of development has been to develop a switchboard which would provide for completing many classes of calls entirely without the aid of an operator, and these new machine switching equipments which you will see today are gradually being introduced into New York, Chicago, and other large cities. This is a large problem in itself and involves not only the completion of calls from machine switching subscribers to other machine switching subscribers, but the completion of calls incoming to machine switching offices from manual offices and outgoing to manual offices. This must be done without reaction on the service or inconvenience to the subscribers and so that the machine equipment and the manually operated switchboards will work together as a coordinated whole.

I do not know of any mechanical device that reminds one so much of the functioning of the human brain as does this mechanism for completing calls following the dialing operation. The completion of a simple call, while quite involved in itself, is by no means the complete problem. There must be a great many other features provided, such, for one example, as where a register is provided on the subscriber's line to register the number of calls under measured rate service. In these cases it is necessary to insure that there shall be proper registration by the machine and the mechanism is so arranged, therefore, that on the completion of the call it will test the line to make sure that everything was normal before registration is actually performed. Similarly, all the way through the completion of the regular and special classes of calls it is necessary for the mechanism to perform just such intricate functions as that described.

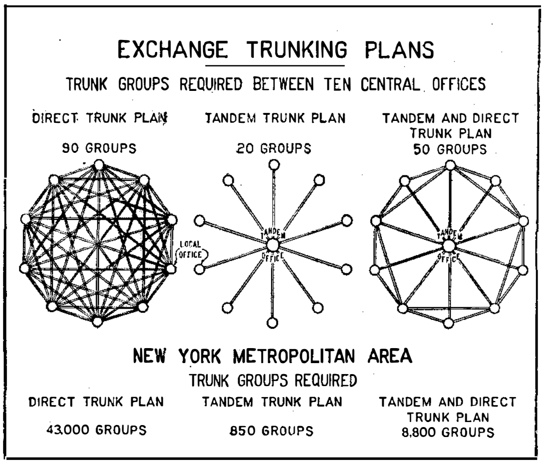

Figure 12

The engineering of the interoffice trunk layout in a city like New York is also an important and interesting problem, not only because of its magnitude but because of the almost unlimited variations which might be employed, a large number of which must be carefully considered in connection with additions to the plant. In opening new central offices, trunk circuits must be provided between each new office and the existing offices and also between the new offices themselves.

Fig. 12 illustrates the range of trunking layouts which might be used. With the 10 offices assumed and direct trunks between each office and every other office, 90 groups of trunks would be required. With the so-called full tandem operation; that is, under an arrangement whereby each office reaches every other office through a central point, 20 groups of trunks would be required. Between these two extremes with some offices reaching certain other offices through the tandem center and certain others by direct trunks, a great many combinations would be possible. In the case assumed 50 groups appeared to be the best combination. The data given at the bottom of Fig. 12 are of particular interest in this connection. As will be noted, if only direct trunks were employed in the metropolitan area, some 43,000 groups would be required. On the other hand, if we followed only the strictly tandem plan, 850 groups would be required but as previously indicated, unwarranted switching costs would be involved. By establishing a plan, however, involving both tandem and direct trunks, the most economical plan can be determined upon and in this case about 9,000 groups of trunks are required. Fig. 13 shows how rapidly the trunk groups increase with the addition of stations and central offices. You can well imagine the engineering problem involved in working out the most effi-

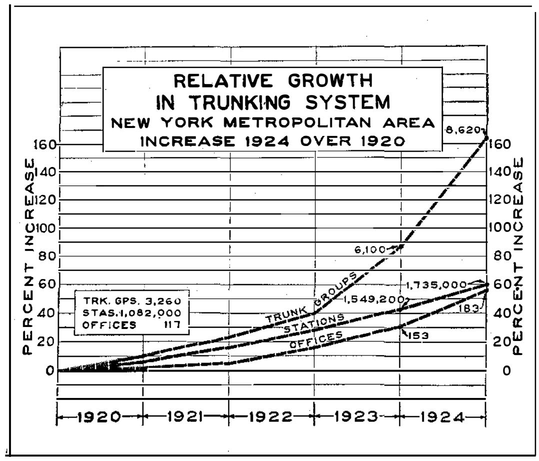

Figure 13

cient trunking plan for a city such as New York or Chicago.

Aside from the layout of the trunk plant itself, the engineering work involves the design and construction of the underground subway system and the design of the physical cable plant. In one year in New York City alone, enough cable has been installed and placed in service to make a cable containing 1,200 wires reaching from New York to Chicago.

The expansion of the metropolitan plant to care for the increase in the number of subscribers also involves, of course, opening many new offices and the provision of new switchboards and additions to the existing switchboards. The matter of selecting the name for a new central office would at first appear to be a simple one, but as indicated by Fig. 14 it is a very involved problem in itself. As will be noted, there are many questions to be considered. One feature relates to the matter of dialing. It is interesting to note from Fig. 14, however, that while the name "John" does not seem in any way to conflict with the name "Knickerbocker," yet these two names could not be used together in the same city because of conflict in the dialing process. Phonetic conflicts are also exceedingly important in telephone operation. In fact, they form one of the most important factors that must be considered in the selection of an office name. Pronunciation of the name must also be easily understood. Thus we find that in the case of the metropolitan area something like 72 sources of names were consulted; for instance, historical works, geographical works, postal guides, telephone directories, and other sources, and out of 100,000 names considered not more than 150 could be used and possibly some of these on further study will have to be eliminated. I have mentioned this detail of operation simply to illustrate the variety of the problems for the telephone engineer and the extent to which he must consider them in order to insure the grade of service we are all striving for.

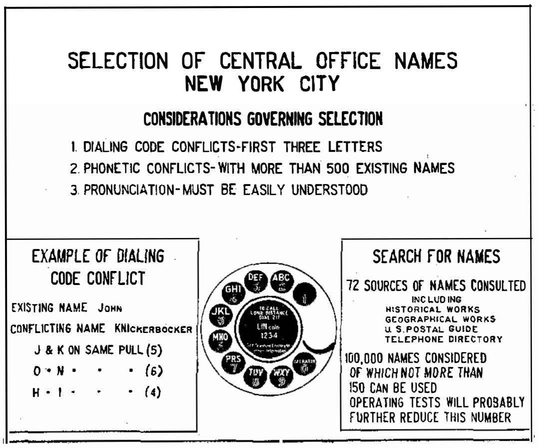

Figure 14

The erection of new buildings and additions to existing buildings is also a large problem, there being 12 new buildings and 21 additions erected in New York during 1923 and 1924. It might be interesting to note that for these buildings and equipments it is necessary to consider not only the proper association of the various elements of the central office unit from the viewpoint of securing satisfactory operation and maintenance conditions, but also to provide for an orderly growth of the different parts of equipment and building. Further, the central office layout must be considered from the point of view of costs which may vary over a wide range

Figure 15—Bowling Green telephone building, New York City

under the different arrangements which might be used. This you will better appreciate from your visits through the offices.

I will next show you a few cases which will illustrate some of the problems in the way of providing building space to house switchboard equipments in these large metropolitan areas.

Fig. 15 is a photograph of the Bowling Green building, located in the extreme lower end of Manhattan Island and which will provide space for switchboard requirements for that part of New York City.

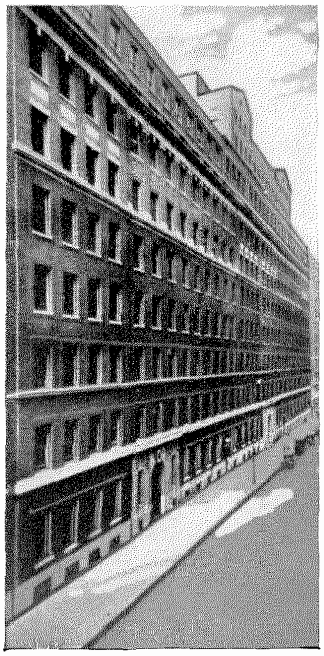

Figure 16—West 36th Street building, New York City

Fig. 16 gives a rather interesting example of another of the large New York telephone buildings, this case being the one located in West 36th Street in the neighborhood of the Pennsylvania Station. This building and equipment involve an expenditure of $15,000,000 and is equipped to serve over 100,000 stations. In other words, we find in this one building and the associated switchboards on subscriber's premises, provision for handling more stations, for example, than are in service in a city the size of Baltimore, with a population of nearly 800,000, giving you a further idea of the problem of providing service in these large metropolitan centers.

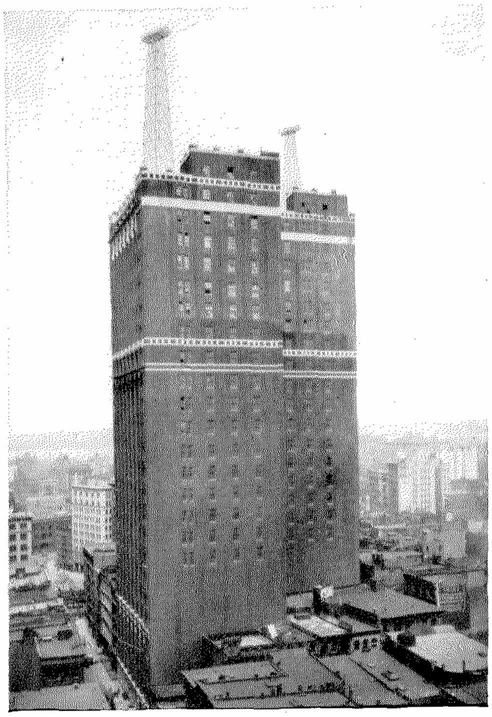

Figure 17—Long distance telephone building, New York City

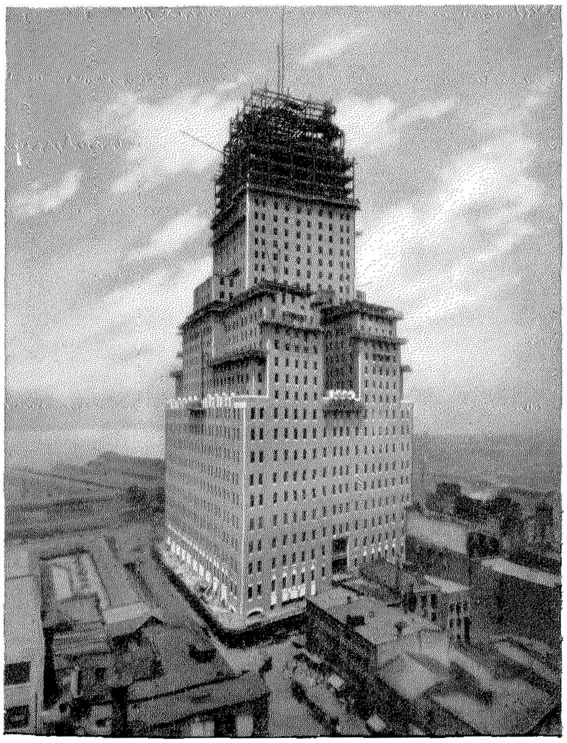

Figure 18—Barclay-Vesey telephone building under construction, New York City

Fig. 17 illustrates the building in New York devoted to the centering of all long distance lines. Facilities are also provided for connecting together the various offices of the city for switching to suburban points through one of those tandem boards of which I spoke, as well as for switching to the great network of toll lines running out to all important points throughout the country. While there are some local switchboard facilities in this building, practically all the space is devoted to handling toll traffic.

Fig. 18 illustrates the new building being built for the New York Telephone Company on West Street in the lower part of Manhattan. This building is designed to house a large number of units of machine switching equipment, and the upper part will be utilized for the administrative offices of the Company. This further illustrates the type of building required in these large centers, and the many engineering problems involved.

I might go on at length, giving one problem after another, by way of illustration, but I think enough has been said to give you a general idea of the nature and great variety of the telephone engineering problem involving, as it does, almost every phase of the mechanical, electrical, and other arts. It is obviously necessary for the engineer not only to consider the technical problems involved in each of these matters, but to a greater extent it seems to me than almost any other situation I have encountered, it is necessary for him to take into account all of the related broad operating and business factors which are naturally to be found in an industry of the magnitude of the Bell System.

Telephone and Telegraph Statistics of the World

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

Telephone Development of the World, by Countries
January 1, 1924

	Number of Telephones					
	Government Systems	Private Companies	Total	Per Cent of Total World	Telephones per 100 Population	Increase in Number of Telephones During 1923 #
NORTH AMERICA:						
United States	—	15,369,454	15,369,454	62.54%	13.7	873,601
Canada	197,926	811,277	1,009,203	4.11%	11.0	65,174
Central America	7,128	10,890	18,018	.07%	0.3	873
Mexico	1,749	48,611	50,360	.20%	0.4	2,431
West Indies:						
Cuba	700	47,086	47,786	.19%	1.5	6,239
Porto Rico	598	10,844	11,442	.05%	0.8	1,071
Other W. I. Places*	3,812	11,302	15,114	.06%	0.3	2,193
Other No. Am. Places*	65	3,600	3,665	.02%	1.1	105
Total	211,978	16,313,064	16,525,042	67.24%	10.9	951,687
SOUTH AMERICA:						
Argentine	—	157,041	157,041	.64%	1.6	13,918
Bolivia	—	2,706§	2,706§	.01%	0.1	—
Brazil	587	93,259	93,846	.38%	0.3	3,734
Chile	—	30,272	30,272	.12%	0.7	1,274
Colombia	—	11,463	11,463	.05%	0.2	1,505
Ecuador	1,891	2,821	4,712	.02%	0.2	432
Paraguay	131	261	392	.002%	0.03	—39
Peru	—	9,140	9,140	.04%	0.2	221
Uruguay	—	24,184	24,184	.10%	1.5	—213
Venezuela	527	10,023	10,550	.04%	0.4	224
Other Places	2,313	—	2,313	.01%	0.5	87
Total	5,449	341,170	345,619	1.41%	0.5	21,173
EUROPE:						
Austria	135,839	—	135,839	.55%	2.1	2,439
Belgium	114,807	—	114,807	.47%	1.5	18,291
Bulgaria	7,283	—	7,283	.03%	0.1	231
Czechoslovakia	103,606	—	103,606	.42%	0.7	10,973
Denmark	10,934¶	281,836	292,770	1.19%	8.7	16,181
Finland	—	80,000	80,000	.32%	2.3	9,500
France	603,786	—	603,786	2.45%	1.5	79,194
Germany	2,242,332	—	2,242,332	9.12%	3.8	169,024
Great Britain and No. Ireland	1,148,095	—	1,148,095	4.67%	2.5	102,167
Greece*	5,400	—	5,400	.02%	0.1	43
Hungary	75,207	—	75,207	.31%	0.9	4,391
Irish Free State (March 31, 1924)	21,268	—	21,268	.09%	0.7	1,658
Italy (June 30, 1923)	99,507	43,096	142,603	.58%	0.4	19,037
Jugo-Slavia*	26,000	—	26,000	.10%	0.2	1,822
Latvia (March 31, 1924)	11,358	—	11,358	.05%	0.6	3,760
Netherlands	192,184	1,084	193,268	.79%	2.7	8,146
Norway	96,972**	70,036	167,008	.68%	6.1	8,698
Poland	69,211	40,937	110,148	.45%	0.4	10,555
Portugal	2,100*	16,759	18,859	.08%	0.3	872
Roumania	31,615	—	31,615	.13%	0.2	515
Russia##	130,278	—	130,278	.53%	0.1	18,278
Spain	28,293	61,707*	90,000*	.37%	0.4	8,050
Sweden	400,691	1,698	402,389	1.64%	6.7	7,854
Switzerland	180,280	—	180,280	.73%	4.6	12,840
Other Places in Europe*	44,182	12,384	56,566	.23%	0.7	5,793
Total	5,781,228	609,537	6,390,765	26.00%	1.3	520,312
ASIA:						
British India (March 31, 1924)	13,628	25,222	38,850	.16%	0.01	—77
China*	69,189	32,236	101,425	.41%	0.03	9,655
Japan (March 31, 1924)	472,805	—	472,805	1.92%	0.8	—46,535§§
Other Places in Asia*	80,093	14,659	94,752	.39%	0.1	20,603
Total	635,715	72,117	707,832	2.88%	0.1	—16,354
AFRICA:						
Egypt	30,863	—	30,863	.13%	0.2	2,505
Union of South Africa¶	65,183	—	65,183	.26%	0.9	4,973
Other Places in Africa*	42,449	1,136	43,585	.18%	0.04	3,202
Total	138,495	1,136	139,631	.57%	0.1	10,680
OCEANIA:						
Australia (June 30, 1923)	281,703	—	281,703	1.15%	5.0	23,226
Dutch East Indies	35,647	2,940§	38,587	.16%	0.1	587
Hawaii	—	16,816	16,816	.07%	6.0	742
New Zealand (March 31, 1924)	111,441	—	111,441	.45%	8.3	4,405
Phillipine Islands*	2,425	12,575	15,000	.06%	0.1	790
Other Places in Oceania*	2,255	430	2,685	.01%	0.1	43
Total	433,471	32,761	466,232	1.90%	0.7	29,793
TOTAL WORLD	7,206,336	17,369,785	24,576,121	100.00%	1.4	1,517,291

Minus sign preceding a figure denotes decrease. * Partly estimated. § January 1, 1923. ¶ March 31, 1924.
** June 30, 1923. ## Including Siberia.
§§ Decrease due to fact that on March 31, 1924, approximately 70,000 telephones were without service as a result of the earthquake.

Telephone and Telegraph Wire of the World, by Countries
January 1, 1924

	Service Operated by (See Note)	Miles of Telephone Wire: Number of Miles	Per Cent of Total World	Per 100 Population	Miles of Telegraph Wire (See Note: Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	41,400,000	61.05%	37.0	1,875,000	29.68%	1.7
Canada	P. G.	2,574,083	3.80%	28.0	270,782	4.29%	2.9
Central America	P. G.	34,661	.05%	0.6	21,812	.35%	0.3
Mexico	P. G.	121,134	.18%	0.9	76,105	1.20%	0.5
West Indies:							
Cuba	P. G.	138,979	.20%	4.4	10,618	.17%	0.3
Porto Rico	P. G.	16,520	.02%	1.2	1,061	.02%	0.1
Other W. I. Places*	P. G.	31,403	.05%	0.6	5,354	.08%	0.1
Other No. Am. Places*	P. G.	7,330	.01%	2.1	9,500	.15%	2.7
Total		44,324,110	65.36%	29.2	2,270,232	35.94%	1.5
SOUTH AMERICA:							
Argentine	P.	481,427	.71%	5.0	175,875	2.78%	1.9
Bolivia	P.	3,254¶	.01%	0.1	6,957#	.11%	0.2
Brazil	P. G.	248,435	.37%	0.8	95,463	1.51%	0.3
Chile	P.	49,441	.07%	1.1	38,090	.60%	0.9
Colombia	P.	15,451	.02%	0.2	14,413	.23%	0.2
Ecuador	P. G.	5,048	.01%	0.2	4,622	.07%	0.2
Paraguay	P. G.	125	.0002%	0.01	1,841	.03%	0.2
Peru	P.	33,180	.05%	0.6	10,401	.17%	0.2
Uruguay	P.	43,585	.06%	2.7	5,029	.08%	0.3
Venezuela	P. G.	27,943	.04%	1.1	6,726	.11%	0.3
Other Places	G.	4,521	.01%	0.9	770	.01%	0.2
Total		912,410	1.35%	1.3	360,187	5.70%	0.5
EUROPE:							
Austria	G.	342,148	.50%	5.2	49,009	.77%	0.7
Belgium	G.	434,960	.64%	5.7	27,695	.44%	0.4
Bulgaria	G.	25,300	.04%	0.5	15,200*	.24%	0.3
Czecho-Slovakia	G.	182,811	.27%	1.3	45,339	.72%	0.3
Denmark	P. G.	692,411	1.02%	20.5	9,352	.15%	0.3
Finland	P.	88,803	.13%	2.6	10,294	.16%	0.3
France	G.	1,739,160	2.56%	4.4	495,000*	7.83%	1.2
Germany	G.	6,466,461	9.54%	10.8	484,514	7.67%	0.8
Great Britain and No. Ireland†	G.	4,493,082	6.63%	9.9	299,301	4.74%	0.7
Greece	G.	5,787	.01%	0.1	23,535	.37%	0.4
Hungary	G.	217,530	.32%	2.7	51,080	.81%	0.6
Irish Free State†	G.	51,711	.08%	1.6	23,205	.37%	0.7
Italy (June 30, 1923)	P. G.	454,309	.67%	1.1	255,000*	4.04%	0.6
Jugo-Slavia*	G.	59,000	.09%	0.5	35,500	.56%	0.3
Latvia (March 31, 1924)	G.	74,971	.11%	3.9	5,647	.09%	0.3
Netherlands	G.	395,925*	.58%	5.5	32,716	.52%	0.4
Norway (June 30, 1923)	P. G.	384,970	.57%	14.1	20,138	.32%	0.7
Poland	P. G.	388,929	.57%	1.4	109,151	1.73%	0.4
Portugal*	P. G.	60,761	.09%	1.0	18,700	.30%	0.3
Roumania	G.	67,783	.10%	0.4	48,308	.76%	0.3
Russia	G.	396,718	.58%	0.3	345,707	5.47%	0.3
Spain*	P. G.	180,000	.27%	0.8	80,730	1.28%	0.4
Sweden	G.	885,427	1.31%	14.7	51,967	.82%	0.9
Switzerland	G.	426,114	.63%	10.9	25,318	.40%	0.6
Other Places in Europe*	P. G.	124,400	.18%	1.5	14,600	.23%	0.2
Total		18,639,471	27.49%	3.8	2,577,006	40.79%	0.5
ASIA:							
British India (March 31, 1924)	P. G.	232,000	.34%	0.1	347,295	5.50%	0.1
China*	P. G.	108,765	.16%	0.03	87,000	1.37%	0.02
Japan (March 31, 1924)	G.	1,297,348	1.91%	2.2	162,397	2.57%	0.3
Other Places in Asia*	P. G.	223,702	.33%	0.2	175,487	2.78%	0.2
Total		1,862,015	2.74%	0.2	772,179	12.22%	0.1
AFRICA:							
Egypt	G.	112,469	.17%	0.6	23,067	.36%	0.1
Union of South Africa†	G.	213,316	.31%	2.9	44,912	.71%	0.6
Other Places in Africa*	P. G.	94,087	.14%	0.1	118,618	1.88%	0.1
Total		419,872	.62%	0.3	186,597	2.95%	0.1
OCEANIA:							
Australia (June 30, 1923)	G.	1,109,990	1.64%	19.6	97,438	1.54%	1.7
Dutch East Indies	P. G.	156,426	.23%	0.3	20,297	.32%	0.04
Hawaii	P.	56,013	.08%	19.9	0	.00%	0.0
New Zealand†	G.	299,264	.44%	22.2	23,067	.37%	1.7
Philippine Islands*	P. G.	28,500	.04%	0.3	9,200	.15%	0.1
Other Places in Oceania*	P. G.	5,430	.01%	0.3	1,381	.02%	0.1
Total		1,655,623	2.44%	2.4	151,383	2.40%	0.2
TOTAL WORLD		67,813,501	100.00%	3.7	6,317,584	100.00%	0.3

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

* Partly estimated. † March 31, 1924. ¶ January 1, 1923. # January 1, 1920.

Telephone Development of Important Cities
January 1, 1924

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINE:			
Buenos Aires	1,811,000	87,213	4.8
AUSTRALIA:			
Adelaide	279,000	19,934	7.1
Brisbane	236,000	15,523	6.6
Melbourne	853,000	61,111	7.2
Sydney	981,000	73,494	7.5
AUSTRIA:			
Gratz	154,000	5,926	3.8
Vienna	1,885,000	87,440	4.6
BELGIUM:			
Antwerp	466,000	18,118	3.9
Brussels	878,000	39,599	4.5
Charleroi	209,000	3,882	1.9
Ghent	279,000	5,398	1.9
Liege	298,000	8,470	2.8
CANADA:			
Montreal	940,000	107,459	11.4
Ottawa	171,000	29,629	17.4
Toronto	611,000	128,496	21.0
CHINA:			
Canton	909,000	2,570	0.3
Shanghai	1,530,000	21,770	1.4
Tientsin	816,000	7,410	0.9
Peking	1,326,000	34,000*	2.6
CUBA:			
Havana	432,000	34,276	7.9
CZECHOSLOVAKIA:			
Prague	690,000	24,291	3.5
DANZIG, FREE CITY OF	369,000	14,615	4.0
DENMARK:			
Copenhagen	746,000	112,709	15.1
FRANCE:			
Bordeaux	273,000	9,565	3.5
Lille	205,000	7,574	3.7
Lyons	574,000	14,116	2.5
Marseilles	598,000	15,986	2.7
Paris	2,965,000	207,861	7.0
GERMANY:			
Berlin	3,880,000	381,291	9.8
Bremen	276,000	25,500	9.2
Breslau	538,000	33,342	6.2
Chemnitz	310,000	18,040	5.8
Cologne	646,000	46,593	7.2
Dresden	600,000	43,841	7.3
Dusseldorf	415,000	30,632	7.4
Essen	447,000	17,708	4.0
Frankfort-on-Main	441,000	45,383	10.3
Hamburg-Altona	1,179,000	120,756	10.2
Hannover	401,000	27,997	7.0
Leipzig	616,000	50,252	8.2
Magdeburg	292,000	17,619	6.0
Munich	643,000	54,716	8.5
Nuremburg	361,000	27,511	7.6
Stuttgart	315,000	27,525	8.7
GREAT BRITAIN AND NORTHERN IRELAND: §			
Belfast	422,000	10,889	2.6
Birmingham	1,311,000	33,460	2.6
Blackburn	256,000	5,784	2.3
Bolton	287,000	6,000	2.1
Bradford	387,000	14,806	3.8
Bristol	417,000	11,618	2.8
Edinburgh	432,000	18,368	4.3
Glasgow	1,298,000	46,158	3.6
Hull	334,000	14,114	4.2
Leeds	552,000	15,668	2.8
Liverpool	1,226,000	43,361	3.5
London	7,282,000	396,524	5.4
Manchester	1,639,000	55,795	3.4
Newcastle	615,000	15,457	2.5
Nottingham	344,000	10,880	3.2
Plymouth	237,000	4,716	2.0
Sheffield	520,000	13,499	2.6

* Partly estimated.

§ March 31, 1924.

Telephone Development of Important Cities—(Concluded)
January 1, 1924

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
HUNGARY:			
Budapest	944,000	49,151	5.2
Szegedin	112,000	2,028	1.8
IRISH FREE STATE:§			
Dublin	399,000	12,500*	3.1
ITALY:†			
Florence	251,000	4,600	1.8
Genoa	305,000	8,347	2.7
Milan	714,000	17,992	2.5
Naples	785,000	6,786	0.9
Palermo	408,000	2,787	0.7
Rome	648,000	14,261	2.2
Turin	509,000	7,953	1.6
Venice	169,000	2,598	1.5
JAPAN:§			
Kobe	695,000	21,690	3.1
Kyoto	658,000	20,474	3.1
Nagoya	655,000	18,127	2.8
Osaka	1,385,000	69,419	5.0
Tokyo	2,265,000	58,324	2.6
Yokohama	447,000	3,949	0.9
LATVIA:§			
Riga	285,000	7,315	2.6
NETHERLANDS:			
Amsterdam	706,000	35,360	5.0
The Hague	383,000	26,599	6.9
Rotterdam	537,000	28,692	5.3
NEW ZEALAND:§			
Auckland	173,000	11,696	6.8
Christchurch	115,000	9,238	8.0
Wellington	115,000	12,751	11.1
NORWAY:†			
Bergen	97,000	8,736	9.0
Oslo (Christiania)	262,000	35,937	13.7
POLAND:			
Warsaw	941,000	31,280	3.3
ROUMANIA:			
Bucharest	357,000	8,940	2.5
RUSSIA:			
Kazan	160,000	1,054	0.7
Kharkov	322,000	2,614	0.8
Leningrad (Petrograd)	1,082,000	14,167	1.3
Moscow	1,543,000	35,078	2.3
Odessa	324,000	1,287	0.4
Goteborg	229,000	26,372	11.5
Malmo	116,000	13,544	11.7
Stockholm	430,000	105,733	24.6
SWITZERLAND:			
Basel	136,000	13,090	9.6
Berne	104,000	11,277	10.9
Geneva	130,000	14,451	11.1
Zurich	201,000	22,976	11.4
UNITED STATES:¶			
New York	5,972,000	1,186,573	19.9
Chicago	2,090,000	691,488	23.8
Total of the 7 cities with over 1,000,000 population	15,789,000	3,080,412	19.5
Los Angeles	995,000	218,662	22.0
San Francisco	650,000	187,452	28.8
Cincinnati	642,000	122,660	19.1
Total of the 10 cities with 500,000–1,000,000 population	6,794,000	1,217,290	17.9
Washington	460,000	110,969	24.1
Minneapolis	430,000	106,798	24.8
Denver	294,000	66,877	22.7
Omaha	215,000	60,870	28.3
Total of the 26 cities with 200,000–500,000 population	7,676,000	1,392,167	18.1
Total of the 43 cities with over 200,000 population	30,259,000	5,689,869	18.8

§ March 31, 1924. * Partly estimated. † June 30, 1923.

¶ In addition to New York and Chicago, the largest cities, there are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups and the development of certain representative cities within each of such groups.

Telephone Development of Large and Small Communities in Important Countries
January 1, 1924

Country	Service Operated by (See Note)	Number of Telephones: In Communities of 100,000 Population and Over	Number of Telephones: In Communities of less than 100,000 Population	Telephones per 100 Population: In Communities of 100,000 Population and Over	Telephones per 100 Population: In Communities of less than 100,000 Population
Australia	G.	180,100	113,216	7.1	3.5
Austria	G.	93,366	42,473	4.6	0.9
Belgium	G.	75,467	39,340	3.5	0.7
Canada	P. G.	376,310	632,893	16.5	9.2
Czechoslovakia	G.	32,254	71,352	3.5	0.6
Denmark	P. G.	112,709	180,061	15.1	6.9
France	G.	302,168	301,618	4.9	0.9
Germany	G.	1,204,003	1,038,329	7.8	2.3
Great Britain and Northern Ireland §	G.	857,738	319,724	3.6	1.5
Hungary	G.	52,743	22,464	4.5	0.3
Italy (June 30, 1923)	P. G.	80,406	62,197	1.5	0.2
Japan (March 31, 1924)	G.	234,926	237,879	2.9	0.5
Netherlands	G.	102,338	90,930	5.4	1.7
New Zealand (March 31, 1924)	G.	33,685	77,756	8.4	8.2
Norway (June 30, 1923)	P. G.	35,937	131,071	13.7	5.3
Poland	P. G.	47,969	62,179	2.4	0.2
Russia	G.	54,200	76,078	1.6	0.1
Sweden	G.	145,649	256,740	18.8†	4.9
Switzerland	G.	61,794	118,486	10.8	3.5
United States	P.	6,733,483	8,635,971	18.2	11.5

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

§ March 31, 1924.

† The majority of this development is due to Stockholm.

Telephone Conversations and Telegrams in Important Countries
January 1, 1923

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent. of Total Wire Communications: Telephone Conversations	Per Cent. of Total Wire Communications: Telegrams	Wire Communications Per Capita: Telephone Conversations	Wire Communications Per Capita: Telegrams	Wire Communications Per Capita: Total
Australia	248,809,000	16,369,000	265,178,000	93.8%	6.2%	44.3	2.9	47.2
Austria	302,954,000*	5,351,000	308,305,000	98.3%	1.7%	46.2	0.8	47.
Belgium	147,401,000	5,703,000	153,104,000	96.3%	3.7%	19.4	0.7	12.0
Czechoslovakia	188,718,000	4,710,000	193,428,000	97.6%	2.4%	13.7	0.3	14.0
Denmark	415,251,000	2,369,000	417,620,000	99.4%	0.6%	123.7	0.7	124.4
France	827,004,000	59,051,000	886,055,000	93.3%	6.7%	20.8	1.5	22.3
Germany	1,851,990,000	51,866,000	1,903,856,000	97.3%	2.7%	31.1	0.9	32.0
Gt. Britain and No. Ireland	924,906,000	63,522,000	988,428,000	93.5%	6.5%	20.4	1.4	21.8
Hungary	303,043,000	4,977,000	308,020,000	98.4%	1.6%	37.7	0.6	38.3
Italy	361,351,000	18,457,000	379,808,000	95.1%	4.9%	9.0	0.5	9.5
Japan	1,741,325,000	59,408,000	1,800,733,000	96.7%	3.3%	30.0	1.0	31.0
Netherlands	318,257,000*	5,397,000	323,654,000	98.3%	1.7%	44.5	0.8	45.3
Norway	298,702,000	4,228,000	302,930,000	98.6%	1.4%	109.6	1.6	111.2
Russia	586,000,000	16,659,000	602,659,000	97.2%	2.8%	4.4	0.1	4.5
Sweden	574,525,000	3,948,000	578,473,000	99.3%	0.7%	95.8	0.7	96.5
Switzerland	135,471,000	2,990,000	138,461,000	97.8%	2.2%	34.6	0.8	35.4
United States	20,500,000,000	185,000,000	20,685,000,000	99.1%	0.9%	184.5	1.7	186.2

NOTE: Telephone conversations include local and toll or long distance conversations. Number of telephone conversations in the United States includes completed messages only.

* Partly estimated.

ERRATA

Article on "Commercial Loading of Telephone Cable," by William Fondiller, July, 1925, issue.

The curves of Figures 6 and 7 (pages 32 and 33), showing the residual and superposed magnetization characteristics, were inadvertently interchanged. To correct this error, it is necessary to transpose these two curves, leaving the subjoined figure numbers and titles unchanged.

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