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Telephone Operating Room of A Concern Which Receives Most of Its Incoming Business Over the Telephone

(See Page 146)

No. 7010 Type Automatic Private Branch Exchange

(*Intercommunicating*)

By B. A. TURKHUD

Bell Telephone Manufacturing Co., Antwerp

AN ideal intercommunicating system should furnish accurate, quick, secret and efficient service; it should be capable of reaching any station on the local network without difficulty; it should provide means for obtaining central office connections with any type of exchange equipment, whether manual or automatic, while permitting restriction of any station to local calls. Transmission losses should not be greater than those encountered on main lines, thus permitting authorization of central office connections; and the cabling scheme should be flexible in order that subsets may be located in any position selected by the subscriber without giving rise to damage to property or unsightly wiring. Means should be provided for tie-line service and the apparatus should be robust and free from marginal apparatus, thus assuring minimum maintenance expenditure.

Existing systems of intercommunication are too well known to require a detailed description in this article. In general, they consist of an omnibus scheme of wiring, the wires from every station being led through the sets at all other stations. A call is made by first depressing the button allocated to the required station and then operating the ringing key. The depression of the button selects the cable-pair, and the operation of the key completes the call. If secret service is to be provided, extra wires are run and either two buttons are set aside for each station between which secret service is required or a marginal blocking relay is added to the sets. Talking and ringing currents are furnished by cable pairs common to all stations. When central-office facilities are required, additional equipment per exchange-line is needed and a different method of operation is employed.

Such systems are in extensive use, but the rapid development of late in methods of telephone switching, and the more exacting demands of subscribers, operating companies and administrations, have strained them to a point where their continued application, in Europe at least, tends to become more and more restricted. The chief criticisms levelled against them are the absence of secrecy on all calls, the cumbersome and inflexible wiring and the difficulties met with when the public telephone system is made automatic. It is perhaps sufficient to state that such systems of intercommunication are not looked upon with favor in Europe and that purchasers of sets must be prepared for a refusal on the part of Administrations and others to grant central office facilities.

The No. 7010 type automatic private-branch exchange manufactured by the Bell Telephone Manufacturing Company, Antwerp, fulfills satisfactorily the requirements outlined earlier in this article. It has capacity for a maximum of 21 lines and is put up in three standard sizes permitting either three, five or six simultaneous connections. In central-office service, the smallest unit makes provision for two exchange lines, the larger one for three such lines, and the largest for five exchange lines.

The P.B.X. is designed on the common battery principle and requires a nominal pressure of 24 volts. Actually, the margins are so wide as to permit accurate operation between 20–33 volts. The transmission circuit is composed of condensers and impedance coils in the form of relays. Calling and clearing from the subset is effected automatically. The A and B wires are used for dialling and talking, and the third wire for supervision.

Figures 1, 2, 3 and 4 show the smallest unit. Figure 1 is a view of the complete unit with dust-covers in position. Figure 2 represents the relay-side of the unit with the top and side dust-cover removed; the substation and junction lines are connected to the soldering tabs shown at the top of the unit. Figure 3 shows the switch side of the P.B.X.; the three switches on the right are the final or selecting switches, whilst those on the left are the hunting or line finder switches. Figure 4 is another view of the relay side, with the mounting plate swung outwards to give access to the battery fuses and terminals mounted on the base board. These terminals are connected to the attendant's box by means of a flexible cord. Under the baseboard is mounted the slow acting relay used for giving the interrupted ring.

The larger unit, switch side, with five connecting circuits is illustrated in Figure 5. The

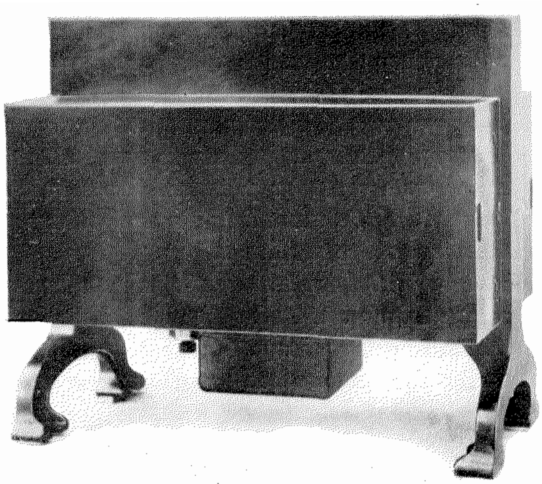


Figure 1—Small Unit Closed

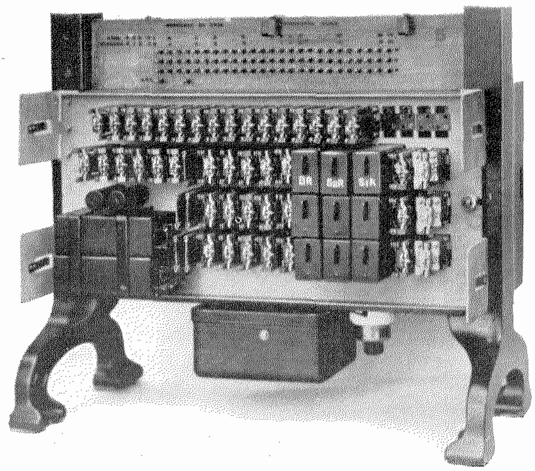


Figure 2—Small Unit—Relay Side

switches mounted in the upper row are the line finders and those on the lower are the selectors. This automatic P.B.X. can be placed on a desk or shelf according to requirements. A typical installation with the unit located on an office desk is shown in Figure 6. The compact attendant's box can be placed alongside, thus allowing the clerk to carry on with his or her clerical duties. Beneath the shelf are mounted the central office ringers and the cable terminal on which the substation and junction lines are terminated.

Apparatus

The substation sets are of two types, the ordinary set and the call-back set. The ordinary set is illustrated in Figure 7. It comprises a dial, ringing button, signal and battery bell in addition to other apparatus common to central battery sets. The call-back set resembles the

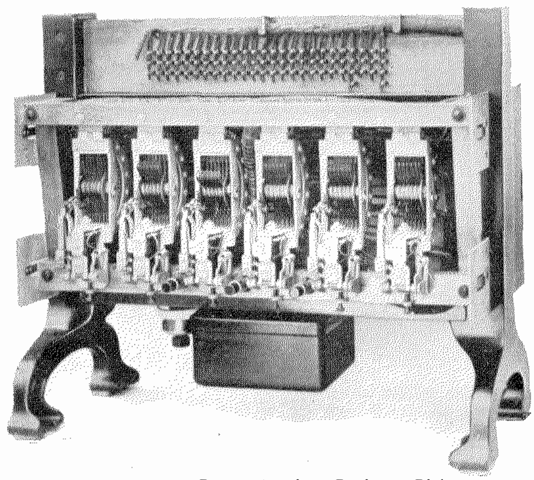


Figure 3—Small Unit—Switch Side

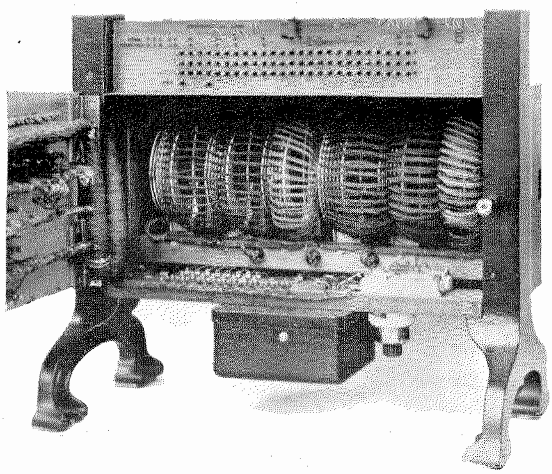


Figure 4—Small Unit—Inside View

ordinary set but is provided with a call-back key and restoring lever. The depression of this key, located on the left of the dial, allows the substation to originate a new call whilst holding the existing connection. The release of the call-back key is effected by means of the key lever.

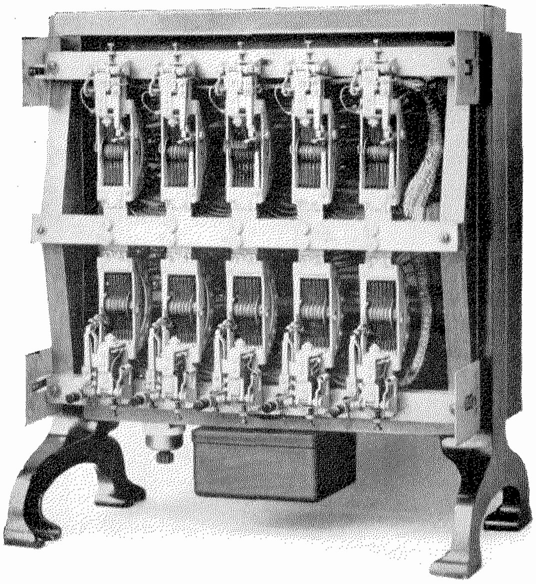


Figure 5—Larger Unit—Switch Side

Figures 8 and 9 show the attendant's set, equipment in this case being provided for two central office lines only. Each line is equipped with a busy lamp and two keys, the upper one of which is the answering key and the lower the release key. The two keys underneath the mechanical signal are known as the local line key and the ringing key.

Figures 10 and 11 show the two types of dials which may be used in the subsets. Figure 10 gives a front and rear view of the uniform break impulse dial with regular numbering. This dial is now standard for all automatic equipments. Figure 11 is a view of the long and short break impulse dial with inverted numbering. This type of dial was used in the earlier No. 7-A M.S.S. equipments and is still in use in Europe and elsewhere. As already stated, either type of dial may be used; but when the long and short

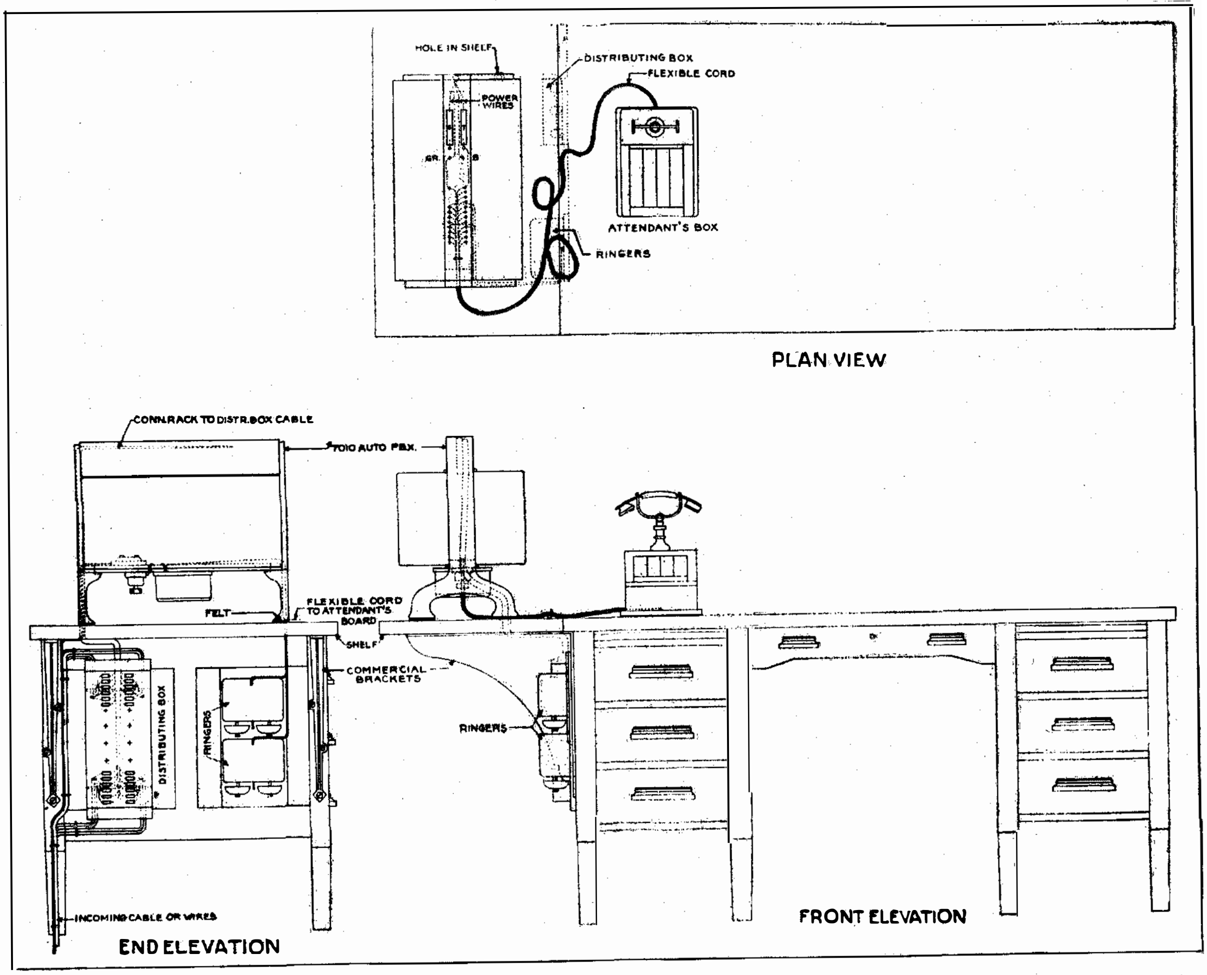


Figure 6—View of Unit on Office Desk

break impulse type is furnished, one additional relay is required per connection circuit (see Figure 14).

The connecting circuit, Figure 14, is composed of 22-pt step-by-step switches, flat type relays [1] and the slow acting relay used as a ringing interrupter. The step-by-step switch, Figure 12, is a self-propelling mechanical device actuated by ratchet and pawl mechanism under the control of an electromagnet. On the energization of the electromagnet a stiff spiral spring is stretched and on the release of the magnet armature the rotor brushes are advanced one step by the recoil of the spring. This arrangement ensures a positive drive capable of easy and accurate maintenance. Double wipers are provided on the rotor thus providing good contact with the arc terminals.

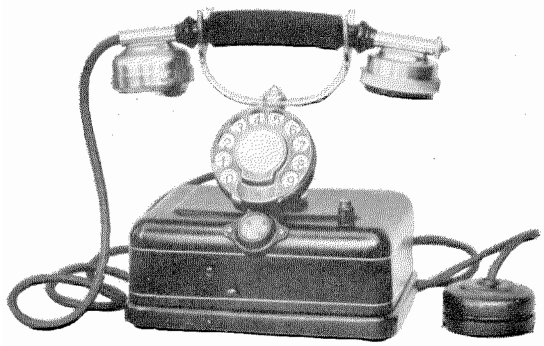


Figure 7—Subscriber's Set


Figure 8—Attendant's Set

[1] For description of Flat Type Relays, see *Electrical Communication*, Volume I, number 3.

The slow acting relay used as a ringing interrupter closely resembles a ringer, but differs from it in that a horizontal spring carrying a weight at each end is attached to the armature. When the armature is attracted to either side, the horizontal spring makes contact with a screw on the opposite side but owing to the resiliency of the spring this contact is of a vibrating character. With normal adjustment, two sets of contacts which are actuated by the armature are closed alternately for periods of 3 and 1½ seconds.

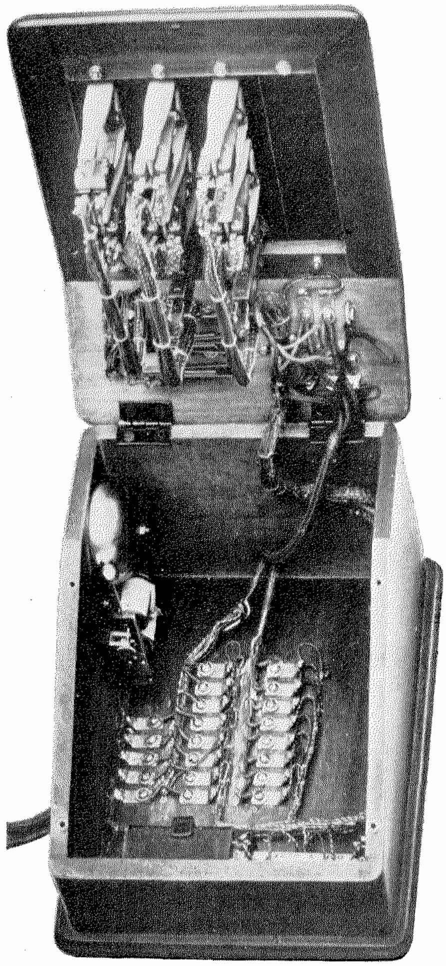


Figure 9—Attendant's Set

Figure 13 shows the cable terminal (distributing box) used with this P.B.X. It is put up in several standard sizes and is interposed between the cables to the subsets and the P.B.X. wiring. Its position can be seen in the elevation view, Figure 6.

The ringers used in connection with calls incoming from the central office consist of the usual 1,000 ohm magneto bell mechanisms. These ringers may be furnished with either two metal gongs, or two wooden gongs or one of each kind, thus giving an audible distinction between the three trunks. Where a larger number of exchange trunks is provided, this arrangement can be replaced by buzzers. The distinction in sound is necessary only in case a substation answers the exchange direct, owing to the absence of the attendant.

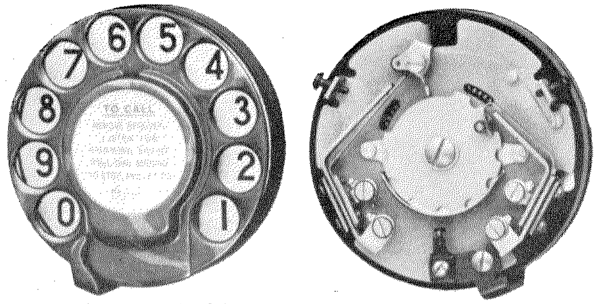


Figure 10—Uniform Break Impulse Dial

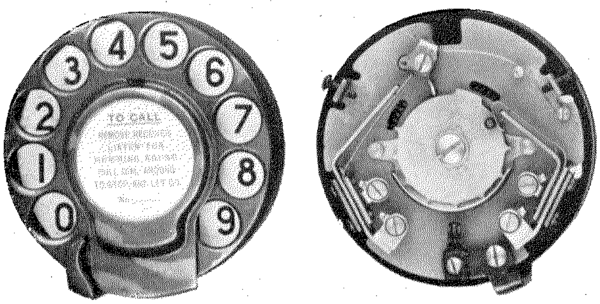


Figure 11—Long and Short Break Impulse Dial

Numbering

The substations are numbered from 1–9 inclusive, and 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 00. The first central office trunk has no number and is generally referred to as "line A". If additional exchange trunks are provided, they receive numbers 1 and 2 or 8 and 9, depending on the dial numbering.

Methods of Operating

The method of operating the board is simple and for a local call is as follows: The calling subscriber removes his receiver, whereupon the mechanical signal on his set shows "white", if a free connection circuit is available. On seeing this signal, the caller dials the number, one digit at a time, and then momentarily depresses the ringing button. If the called substation is free, the signal will continue to show "white" when the ringing button is depressed. If, however, the called line is busy, the "white" signal will disappear when the ringing button is depressed. Release takes place when the calling subscriber restores his receiver.

If the calling subscriber wishes to make a call to the central office the procedure is similar except that instead of dialling he depresses the ringing key. If the first trunk to the central

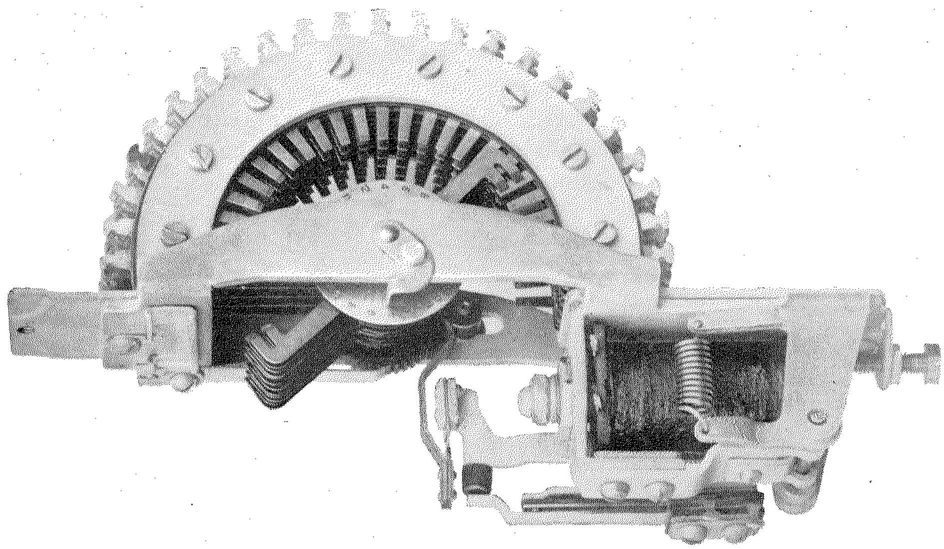


Figure 12—Step by Step Switch

office is free it will be picked up and the signal will remain "white" when the key is down. If, however, this trunk is busy, the calling substation releases the button and dials a digit which gives one dial impulse (this digit may be 1 or 9 according to the dial numbering). The depression of the ringing key then indicates the

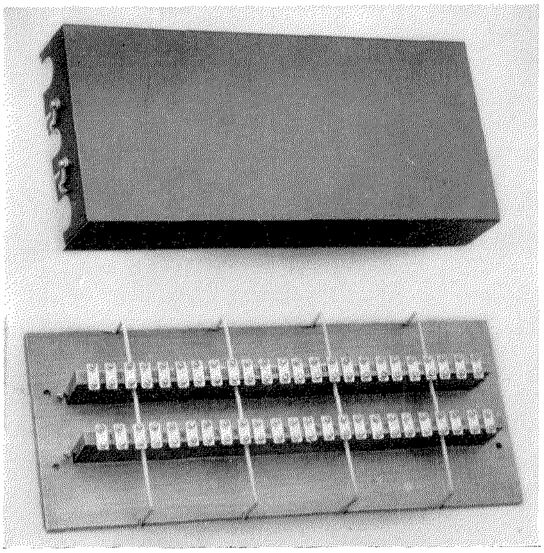


Figure 13—Cable Terminal

condition of the trunk. This procedure of dialling one digit, etc., is continued until either a free trunk to the exchange is found or until all trunks have been tried.

An incoming central office call is signalled by the ringing of one of the central office ringers. The attendant then throws the corresponding answering key, AK, Figure 14, and obtains the necessary particulars. The guard lamp GL, associated with this central office line, lights. The attendant then throws the local line key LLK, and calls the required substation through the automatic P.B.X. When the called station replies, the attendant gives notice that he is wanted on such and such a central office trunk and then restores both keys to normal. The called station originates a new call and directs it to the particular trunk quoted by the attendant by making a call to the particular trunk. On obtaining this connection, the guard lamp in the attendant's set is extinguished and listening-in by the attendant is rendered impossible. If the attendant is unable to reach the called station and the call is abandoned, the connection can be released by restoring the answering key and operating the release key RK.

If the means for originating or receiving central office calls is not to be provided for certain lines, this can be provided for by disconnecting a wire from a terminal on the line finder arc to which such restricted subscribers are connected.

If the attendant, on behalf of a calling subscriber wishes to make a call to the central office, one of the answering keys is thrown. If this trunk is free, the guard lamp GL lights. Having obtained a free trunk, the release key RK is then operated and the attention of the central office is gained. The attendant forwards the call either by dialling or verbally and then restores the release key. When the called central office subscriber answers, the attendant advises the calling subscriber in the same way as for incoming calls.

In certain cases it has been specified that on incoming calls the attendant shall first verify that the station taking the central office trunk on which the call is waiting is the required station. Means have therefore been provided by which the guard lamp is made to burn dimly when the central office line is seized by a station. The attendant then enters the circuit and if the station is the one required, the connection to the central office is completed, by restoring a key.

For night service, the central office ringers are multiplied in various parts of the building thus enabling any substation to answer an incoming call.

Where a tie-line circuit is provided, the method of operation is similar to that for an outgoing call to the central office. The substation obtains a connection circuit, dials the tie-line number, which takes the place of a central office trunk, and depresses the ringing button. If the tie-line is free, the signal on the set remains displayed and the caller receives a tone. When a free connection circuit is picked up at the distant P.B.X., the tone is removed from the line and the calling station then sets up the call as if it were a local call. If the distant substation is busy, the calling station receives a tone.

This tie-line circuit operates on a bothway basis and can be so arranged, if necessary, as to

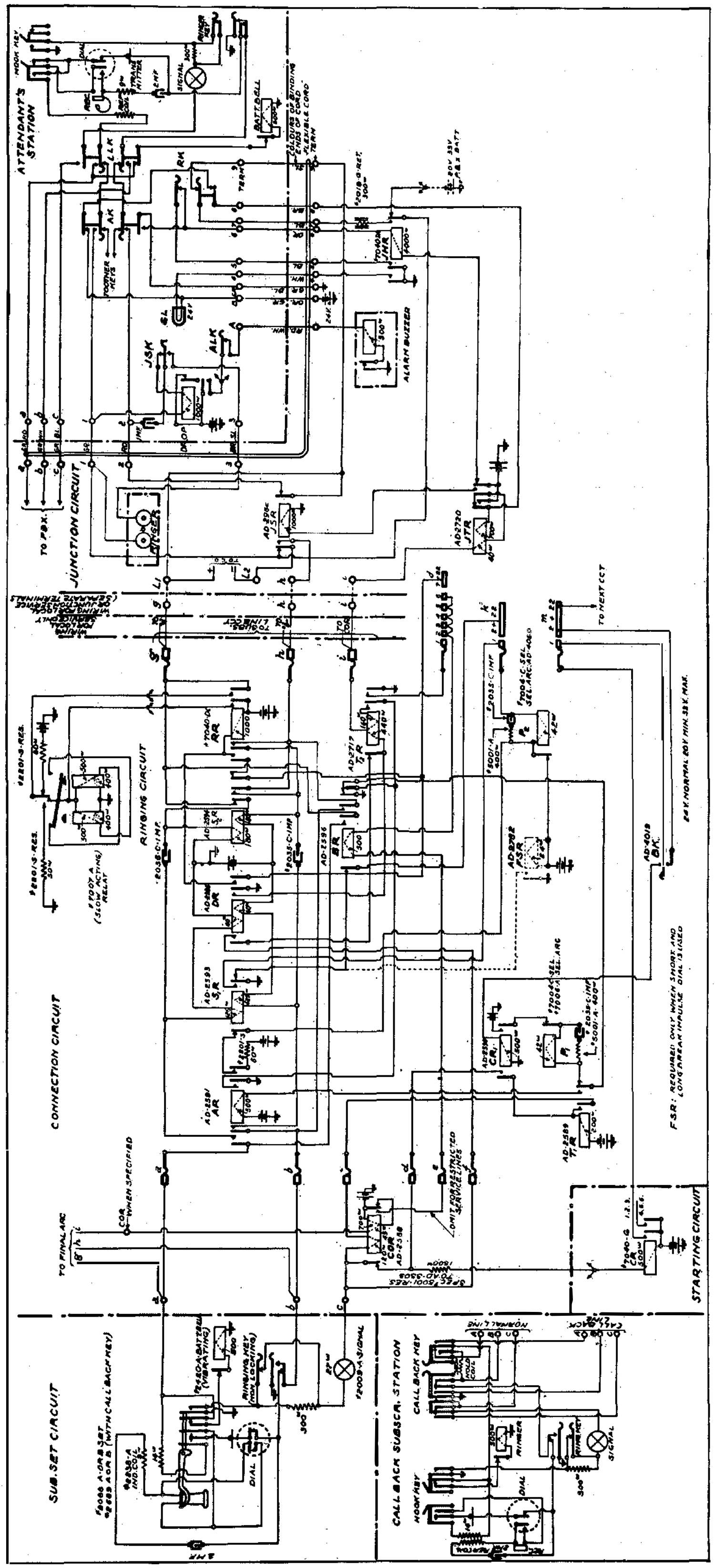


Figure 14—No. 7010 Automatic P.B.X. Circuits

make it impossible to obtain central office connections over the tie-line.

Power Plant

The power plant consists of a 12 cell accumulator battery having a capacity of from 14 to 20 ampere hours. This battery may be charged in a variety of ways either over the central office lines, or over special cable pairs, or through a bank of lamps if the public supply is D.C. or finally by means of a rectifier in the case where the public supply is A.C.

An idea of the current consumption for various types of calls can be obtained from Figure 15, which is self-explanatory.

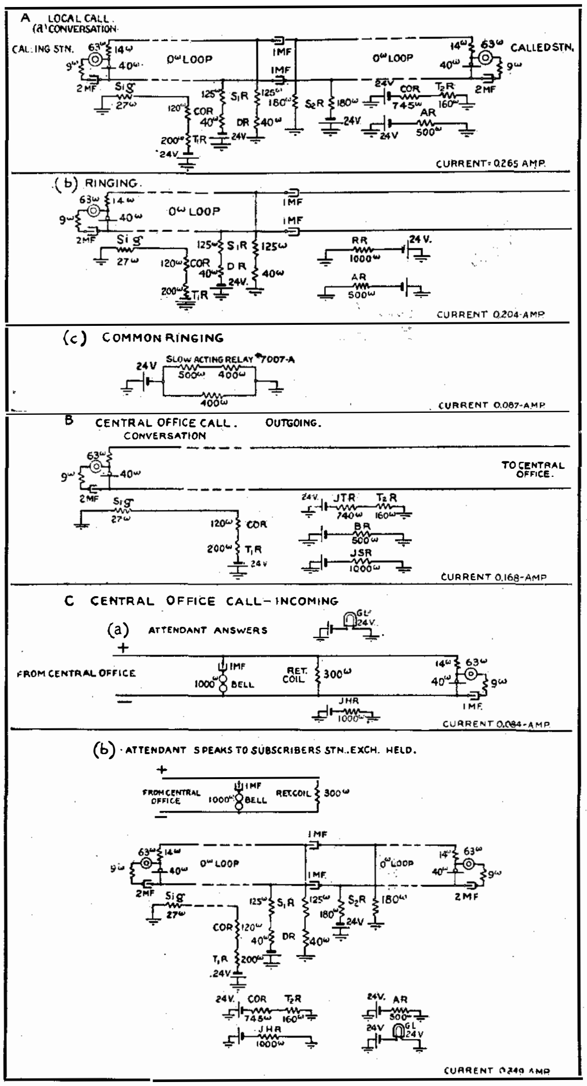


Figure 15—Current Consumption Data

Circuit Description

Figure 14 shows the circuit of the P.B.X. and the attendant's unit. Space does not permit the tracing of all circuits in detail nor is this necessary for the purposes of this article. A few notes, however, on the operation of the circuits may be helpful.

When a substation removes the receiver, a "ground" is placed on the third wire through the supervisory signal. The starting relays CR (common) and CR_1 (individual) operate but the signal does not, owing to the series resistance. The line finder brushes now move forward one step at a time until on reaching the calling terminal the test relay T_1R is energized over brush "d" and in series with the signal which also is actuated. The line finder magnet-circuit is now opened and the brushes remain on the line. Relay AR then operates and closes the circuit for relays S_1R and DR over the substation loop. Relay S_1R operates but DR is wound differentially and remains normal. With S_1R operated, the final selector magnet receives current and advances one step. The movement of this switch brings about the release of CR and CR_1, thus opening the short circuit across the cut-off relay COR. Relay COR then operates in series with T_1R and the line is made busy.

The substation on seeing that the signal is actuated proceeds to dial the number wanted. The dial impulses are received by S_1R which operates in unison and causes the final selector to step forward a corresponding number of steps. It should be noted that the final selector magnet P_2 is energized and remains operated during the time that S_1R rests on its back-contact, with the result that the brushes are not propelled forward until S_1R is again energized. This arrangement precludes the possibility of troubles due to variations in the duration of the dial impulse. In the case where the long and short break impulse-dial is provided, relay FSR is provided. This relay operates during the interval that S_1R is on its back-contact and locks in series with the final selector magnet and its interrupter. When P_2 is fully energized, its interrupter-contact is opened, this series circuit is broken, FSR is released and the final selector brushes are advanced one step.

After the substation has finished dialling, the ringing key is depressed momentarily. This key connects "ground" to one side of the line-circuit and opens the loop through the set, thus upsetting the balance of relay DR which now operates and remains up until the key is released. Relay DR connects a "ground" to the high-resistance winding of the final selector test-relay T_2R which then operates if the called line is free. When T_2R operates, it closes a circuit through its low resistance winding and the winding of the cut-off relay. When relay COR opens its back contact, the short circuit across its high resistance winding is opened and both windings are placed in series. This combination of resistances is such that this terminal is marked "busy" to any other final selectors. With T_2R operated, a circuit is closed for the ringing relay RR over brush "d" of the final and a front contact of DR. Relay RR also closes the circuit of the slow acting relay, used as a ringing interrupter, with the result that battery and "ground" are connected alternately and periodically to the "g" brush. The battery bell in the set is thus actuated.

When the called station answers, relay S_2R operates and breaks the locking circuit of RR. The talking circuit is now closed over the front contacts of S_2R.

On the release, the receiver is replaced and relays T_1R, COR, AR, T_2R and S_1R are released. The final selector-magnet then operates in series with its interrupter, and the switch is reset to normal.

If the called line is busy, T_2R does not operate when the ringing button is depressed. As a consequence, the "ground" connection to the winding of T_2R—furnished over the front contact of DR—is extended to the "f" brush of the line finder. This "ground" short-circuits the signal at the calling set and causes the "white" signal to disappear.

For calling to the central office, a connection circuit is picked up in the manner already described and the final switch advances one step. When the caller depresses the ringing button, relay DR is energized and the line is tested. If free, relays T_2R and JTR operate and lock; the line is made busy and relay JSR is energized, thus opening the bell and condenser circuit across the trunk. If the line is busy, T_2R does not operate and the supervisory signal at the substation is withdrawn. The substation then tries the next line in the manner already described.

The operation of relay T_2R closes a circuit through relay BR which then switches the local relays out of circuit and provides a pure metallic circuit, free from bridges. On the release, relays T_1R, COR, BR, T_2R and JTR are de-energized.

On receiving an incoming call from the central office, the attendant throws the answering key AK. This makes the central office line busy, and also causes relay JHR to operate, whereby a holding coil is placed across the central office trunk. The attendant ascertains the requirements and throws the local line key LLK. The depression of this key connects up a free connection circuit, and the attendant then obtains the wanted subscriber and advises him of the call and of the number of the central office trunk over which the call has been received. This done, the attendant restores both keys. The restoration of key LLK, with key AK normal, releases the local connection and battery is again connected to relay JTR in readiness for the call about to be made to this trunk by the required station. The substation meanwhile dials the trunk assigned by the attendant. This results in the operation of relays JTR and JSR, the release of relay JHR, the extinction of lamp GL and the removal of the holding coil from the trunk. In addition, the ringer is removed from the line and the attendant's set is locked out, thus ensuring secrecy.

The release follows the same sequence as in the case of an outgoing call to the central office.

Tie-Line Circuit

The apparatus-box circuit for a bothway, automatic in and out, tie-line is shown in Figure 16. The circuit is connected to the tie-line on one side and to the arcs of line finders and finals on the other side. When such facilities are specified, a small wiring change is made in the substation sets. This change involves connecting the condenser directly to the "b" wire instead of by way of the ringing key, so that when the key is depressed, the receiver-circuit is bridged across the line but the microphone circuit is opened. This change is necessary to prevent the shunting out of the free tone from the distant P.B.X.

To make a call, the substation dials the number allotted for the tie-line and depresses the ringing button. If the tie-line is free, relay T_2R (Figure 14) operates in series with relay AR, Figure 16. Relay C_1R (home P.B.X.) then operates in series with relays STR and DTR impulses are received on relay STR and repeated to the connection circuit. On the depression of the ringing button, relay DTR operates and connects the battery to the "b" terminal of the line finder arc. This battery causes relay DR in the connection circuits to become energized and the wanted line is tested in the regular way. If the line is free, relay SGR in the ap-

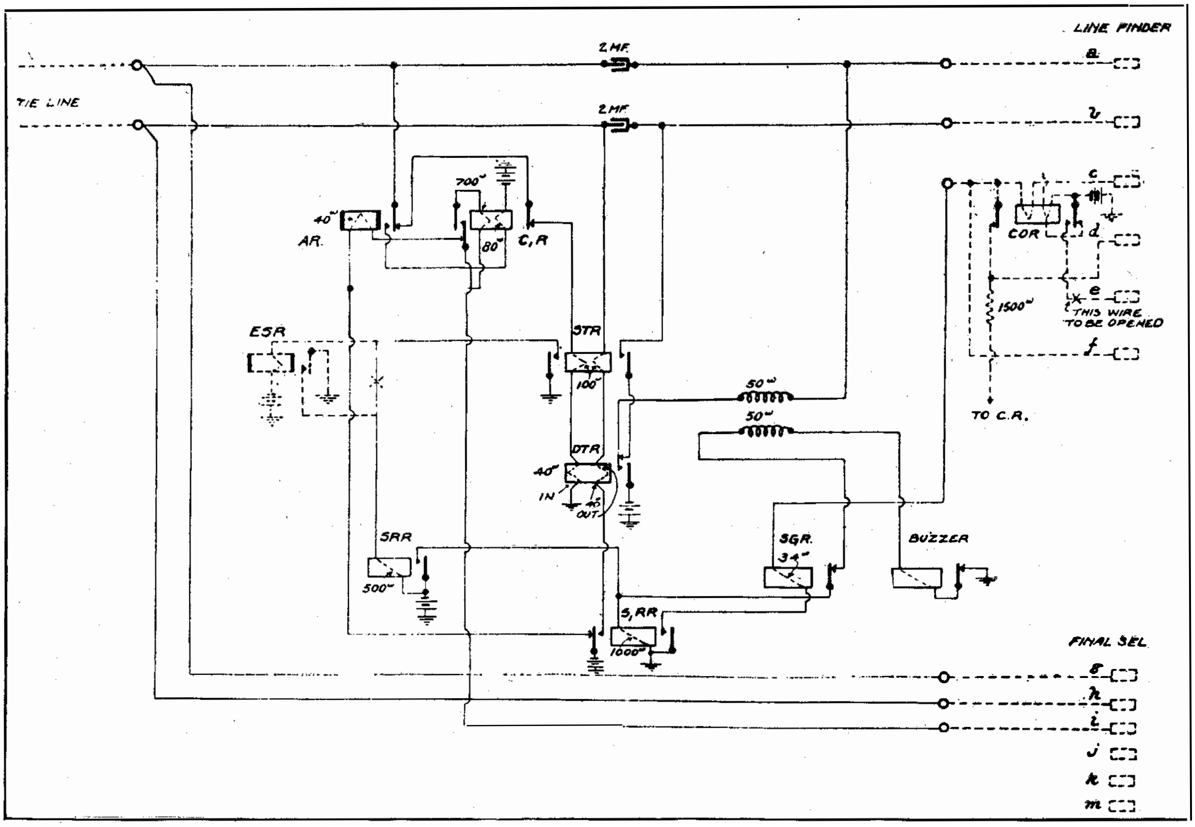


Figure 16—Bothway Tie Line Circuit

in the tie-line circuit at the distant end. Relay C_1R locks over its second winding and disconnects AR, which after a short interval opens its front contact. Meanwhile, at the distant end, relays STR, SRR, and S_1RR operate; relay DTR is differential and is normal. Relay STR loops the "a" and "b" lines to the line finders, relay S_1RR closes the starting circuit for the finders which rotate and pick up the line in the usual manner. During the hunting, a tone is placed on the line. When the tie-line is picked up relay SGR operates and cuts off the tone. The subscriber now dials the wanted number and then depresses the ringing button. The dial paratus box circuit remains energized; but if busy, this relay releases and a tone is given to the calling station.

On the termination of the call, the receiver is replaced and STR is de-energized. The apparatus-box circuit together with the connection circuit is then restored to normal.

Conclusion

The facilities furnished by this automatic P.B.X. may be summarized as follows:—

1. All calls are secret.
2. Connections are accurate, quick and automatic.

3. Any or all substations may originate central office calls without the intervention of an attendant and may set up the central office switches or call the manual A operator.

4. Any local line may be debarred from making or receiving central office calls.

5. Calling back facilities for important substations.

6. Incoming central office calls can be directed to the proper substation without the help of a full time operator.

7. Automatic clearing to central office.

8. Continuous service day and night without attendance.

9. Visual supervisory signals at substations.

10. Interrupter automatic ringing is secured by the momentary depression of the ringing button.

The Telephone as an Economic Instrument*

By F. E. RICHTER

American Telephone and Telegraph Company

Editor's Note: This paper emphasizes the importance of the telephone as an aid to the efficient conduct of business and cites a few instances of the use of the telephone as an economic instrument. The author's conclusion that the telephone seems destined to make far greater contributions in the future than in the past to the economic development of the country is quite obviously justified when applied to the relatively intensive telephone development of the United States and it seems apparent that it should apply with even greater force to many other countries.

THE telephone was originally developed as a business instrument, just as was the steam railroad. The longer it has been in existence, the more invaluable it has become in this role. Its importance may be assessed by trying to imagine what would happen if business were suddenly to be deprived of telephone service. The business uses of the telephone, to be sure, have not dominated the operations of the telephone industry to quite the extent to which freight traffic has dominated the operations and generally governed the earnings of the railroad industry. At the end of 1924 two-thirds of the 16,209,000 telephones then in use in the United States were residence stations, and only one-third business stations, though business uses, from either residence or business stations, are doubtless responsible for the greater part of the traffic. Let us first refer, in passing, to a few aspects of the social significance of the telephone, a factor which is by no means without its relation to economic development and evolution.

No one needs to be reminded of the social importance of the telephone. Again, one may try to imagine what would happen to the social life of any community out of whose homes all telephones were taken. On the one hand, it makes neighbors of persons at opposite ends of a large city and thus helps to make city life more pleasant. On the other hand, it is fair to say that suburban development on the fringes of our great cities has been encouraged by the ability to secure there, as elsewhere, the advantages of telephone service, without which the suburbs would seem further away from cities than they are. This is only to recite the obvious, and it does not seek to give the telephone credit which belongs to other agencies which bind communities together and serve to annihilate distance.

In the protection of life, health, and property, in the large urban centers, the telephone has, of course, been among the things which have helped to make life feasible in those communities. In the functioning of police departments, fire departments, and indeed all the other public agencies which safeguard existence in our cities, the telephone is playing an increasingly important part.

Then, when we turn from the cities to the rural communities, it is obvious that the telephone has been a contributing factor toward making farm life less isolated and therefore more desirable than it would otherwise be. It has been estimated that there are today not far from two and three-quarter million telephones on the farms; and among the states of the Union, the greatest density of telephones per capita is not in one of our great industrial states but in the great farming state of Iowa. It can be said with much assurance that many a young progressive farmer would not be on the farm today if it were not for the fact that the telephone keeps him and his wife in touch not only with their neighbors, not only with stores on Main Street, but with the country at large outside of their own particular community. For the women on the farm, no less than for the men, the telephone has done much to make life more worth living.

The Peculiar Function of the Telephone

The telephone is the only instrument we possess which permits a personality to be projected immediately, almost anywhere in the whole country, into the next room or into a city three thousand miles away. The railroad gives speed of transportation, but the trans-

* Published in *Bell Telephone Quarterly*, October, 1925, and reprinted by permission.

portation of personality is at best at the rate of about a thousand miles a day and with only one definite objective. The telegraph gives more nearly instantaneous communication but does not permit an interchange of ideas except with some delay and generally through the operation of intermediaries. The telephone connects directly two personalities who may talk to each other and use their own language as freely as if they were face to face, and permits a personality to be transported within a length of time measured by minutes instead of by days, successively to Portland, Maine, to Portland, Oregon, to New Orleans, and to a building just down the street.

Such an agency as this must necessarily have had as its principal result the speeding up of economic organizations and functions, and it would be difficult to mention any of its direct or indirect economic effects which are not directly or indirectly a result of the telephone's acceleration of processes. As an accelerator of processes, the telephone has become a definite economic and industrial force, functioning at different times in opposite directions. For instance, it may work in the direction of centralization or in that of decentralization, according as its various effects have caused the economic organism to adapt itself to the use of the new tool in one way or the other. In so far as it has helped to lessen the isolation of farm life, or helped to increase the attractiveness of suburban life, it has assisted in the decentralization of population. On the other hand, the modern skyscraper is an excellent example of the centralizing influence of the telephone. The skyscraper is unthinkable without the telephone, just as it could not exist without high-speed elevators. The intensive development of lower Manhattan Island, where tens of thousands of people work within a square mile, would clearly not be feasible if all the messages that go between these people had to be taken by hand. The elevator space that the messengers would require would leave little space for offices, and the business day would not be long enough. This extreme centralization is possible because instantaneous communication can be had between any of the thousands of pairs of individuals in such a congested district who want to communicate with each other every day, and to whom even the telegraph would be an intolerably slow medium.

The Telephone in Production

Economic activities, other than that of consumption, may be divided into the categories of production and distribution, and the contribution of the telephone to economic activity may be studied under these heads. Within the field of production, we may consider the factors of industrial organization, plant organization, and transportation.

Industrial organization involves the geographical location of industries and their development, horizontally and vertically. It is probably correct to say that the telephone has had less influence in industrial organization than in some other branches of economic activity. The location of industries is naturally affected by many special influences, such as location of raw materials, or of personnel, or of markets, or of transportation facilities, or by historical or traditional factors of one sort or another, with physical or cost factors dominating the selection of sites, and economic friction putting important obstacles in the way of easy removal of operations from one place to another. Industry, in other words, has frequently to go where transportation facilities or other economic resources can be found, while communication, through the telephone, can be brought to an industry, almost wherever it may be established. Just because of this, however, the telephone has its influence in plant location. For example, New York or Chicago or some other large center may seem the logical place for a manufacturing plant to be. The telephone, by making available instantaneous communication with outside sources of supply of every kind, frequently makes it possible to locate the plant, as, for example, the Western Electric Co. plants are located, in suburban districts where land is relatively cheap, instead of in a high rent district nearer to or in the heart of the city.

And if the telephone is a factor in the location and operation of a single plant, it is not less important in the case of an enterprise consisting of a number of scattered units, whether integrated or otherwise. An increasing number of concerns, not content even with ordinary telephone facilities, are leasing and installing private telephone lines between various producing units, which are in daily use in facilitating unit control of far-flung and sometimes highly integrated enterprises. Here is a clear case of the instant transmission of personality, the characteristic function of the telephone, operating to speed up and otherwise assist industrial activity and therefore economic development.

Many enterprises consist of producing units whose location is determined by one set of factors, wliile another set of factors dictate the location of the executive headquarters or the selling organization somewhere else. For such concerns, the telephone affords a high degree of control of operations to headquarters and of contact between sales and production forces. Earlier this year a trade paper carried this advertisement:

"We moved a 55-acre brass mill 100 miles.

"A private telephone line direct from our Waterbury mills to our New York offices places our mills next door to us, for offices and mills are only a fraction of a second apart by wire.

"We pick up the telephone and talk to Waterbury, just as we would talk to someone here in New York."

The lesson of this and its bearing on the question of acceleration of processes, decentralization, and economies of operation, are obvious. The whole thing sums up in the statement that the telephone is a potent factor in permitting each economic function to be performed where it can be done to best advantage.

In the matter of plant organization, or the internal planning of operations as against the external contacts, we find that the telephone has been an important instrument of control and regulation. A 55-acre mill (whether the 55 acres of floor space are all on one level, or not), an automobile plant in Michigan that extends for a mile or more along one street, a Hawthorne with its 25,000 or so employees, such works as these require every device that will economize executives' and supervisors' time and energy, and at the same time permit constant and instant control over production-flows. The smooth working of such a plant without the telephone is hardly to be conceived, at least at present speeds of operation and rates of output. Furthermore, where land is cheap enough so that plants can be strung out over large areas and advantages secured thereby which would not be secured by building four or five stories into the air, the function of the telephone in economizing time by means of instant communication between all parts of the plant is especially apparent.

If nothing is said at this time of the telephone as a means of facilitating purchases of materials, it is because buying is simply the other side of selling, and the use of the telephone in selling and in trade generally will presently be examined in connection with the economic function of distribution.

Since production is in essence changing the form and place of matter, we may consider transportation as being part of the process of production, though, to be sure, it is clearly related to activities of distribution. The foremost agency of transportation in this country is its railroad net. In railroading, the telegraph has played a far greater part than the telephone, and is today still the principal means of control of railroad operations. Nevertheless the telephone has found a definite place in the field of train dispatching and its importance, either in place of or as a supplement to the telegraph, is growing year by year. The greater certainty and flexibility of the telephone, the advantage of person-to-person contact between division headquarters and station operators, without depending on the intermediation of telegraph operators, and the fact that any two people who speak the same language can use the telephone, whereas it takes persons skilled in the art to operate telegraph keys, have been among the things that have brought this about. In local transportation enterprises, as well as in other local public utilities, it goes without saying that the telephone is an indispensable tool of control and regulation. Perhaps the outstanding example of telephone control of transportation is in the most mobile form of transportation facilities, namely, the taxicab business. In the big cities where large companies operate fleets of taxis and competition is of the keenest, the development of the use of the telephone for the ordering of cabs and for their mobilization at proper points to take care of expected or unexpected peak loads, has been quite remarkable. In view of the fact that each cab must operate, not along selected routes, but at the whim of the momentary occupant, as to time and direction of movement, it is easy to see how great assistance the telephone brings to that business, in enabling chauffeurs, whenever their cabs are vacant anywhere in the city, to get in touch immediately with headquarters for orders.

The Telephone in Distribution: Markets

The end and aim of economic production is distribution or selling at a profit. The history of the development of markets is a story of the widening of market areas. The telephone, during the past generation, has been a most powerful factor in such development. In the local town markets or bazaars of olden days or of undeveloped countries in more recent times, a market signified just a small aggregation of buyers and sellers in one locality. The smaller the market area and also the less standard or standardized the commodities, the more likely are price divergences to obtain and to persist between markets, even irrespective of differences in costs. In time certain towns began to develop as centers for certain trade markets in standard commodities, raw or worked-up. This was the first approach to anything like a national market, and it was necessary for buyers to resort to these centers to supply their wants, just as buyers came to the local markets in the old days, or as buyers have sought out sellers at retail in all ages. Today some commodity markets are not only country-wide but even world-wide in their scope; and economists, in their theoretical analyses of demand, supply, and prices, are wont to define a market as any area within which a uniform price obtains for a given article sold under given conditions.

In those commodities where standardization and grading were most applicable and where at the same time a broad market existed and a large supply could reasonably be counted on, exchanges developed such as the grain, cotton, coffee, and metal exchanges, and the stock exchanges. This meant daily instead of periodical contacts between groups of buyers and sellers and provided markets which responded sensitively and quickly to current news affecting either supply or demand of the commodities in question. At the same time, through the machinery of future contracts, these markets were equipped with stabilizing influences to temper the advances and declines of prices which might result from current economic developments. Markets as highly organized as these naturally led the way in the adoption, and adaptation to their needs, of all advances in the arts of news-gathering and of communication. A lone merchant with a monopoly of the market, dealing with a lone, uninformed customer can deceive his customer about conditions of supply or demand, about costs, or anything else. But when groups of intelligent traders vie with each other in a market for standardized commodities, the amount of advantage which any man can take of any other varies inversely with the ability of the former to secure news more quickly and act more quickly and intelligently than the latter. The telegraph and telegraphic devices of one sort or another, were therefore seized upon by such markets as Wall Street, and then the telephone; and at the present time there is nowhere more intensive use of the telephone than in Wall Street. The Stock Exchange as it is organized today could not function without the telephone. The same can be said of the other big speculative markets, the only difference being one of degree, which reflects chiefly the difference in the volume of transactions. It goes without saying that the banking and credit operations which accompany the functioning of these markets as well as of all other business make great and constant use of the telephone and could today hardly be carried on without it.

Wholesale "Shopping" by Telephone

Standardization and grading were spoken of in the preceding paragraph. They are essentials for the establishment of exchange markets on which valid contracts for future delivery can be made. By no means have all commodities, which on these grounds might be eligible for exchange dealings, been dealt in or at any rate had their principal markets on exchanges. In this country, for example, the greater part of the production of the three principal non-ferrous metals, copper, lead, and zinc, could well be traded in on the New York Metal Exchange or some other board, but is in fact not so dealt in. The market for these metals has for years been primarily a telephone market; consumers have "shopped" over the telephone with quite as much assurance as, and with much greater speed and less effort than, with personal office-to-office visits. A very large part of the whole refined copper output of this country, for example, is bought and sold by telephone between a relatively few offices in New York City. This is typical of the contribution that the telephone has made in facilitating distribution and the growth of market areas, and incidentally, of course, in the encouragement of standardization. The significance of all this lies not merely or even primarily in the volume of transactions consummated over the telephone, but in the fact that the telephone has been the final and perhaps, in certain cases, the principal factor in broadening the market area, the area in which a substantially uniform price prevails, and in making it at least country-wide if not international.

Back of the big commodity exchanges are the dealers who actually handle the commodities which are traded in on the exchanges. It may not be amiss to cite just a single example of the way in which the telephone is called into play by one set of dealers. In the South, cotton is collected from the farms into towns, and buyers visit these towns to purchase the cotton. These buyers can do a much more intelligent job if they are in constant touch with quotations on the big markets, and, as a matter of fact, they do keep themselves continuously in contact with principals and with the markets by means of the telephone. This means quite a different situation from that in which the buyer found himself isolated from principal sources of information before the use of the telephone for keeping contact was possible for him. The function of the telephone in eliminating or reducing risk is obvious.

Risk Elimination; Local Decentralization

At this point we may call attention to the utility of the telephone in this same function of risk elimination, under two quite opposite sets of conditions. Great is the contrast between the feverish times of early 1920, when production was being pushed to the utmost and business men were scrambling for goods, credit, and labor, in order to produce and market as much as possible, as promptly as possible, so as to take advantage of the high prices prevailing, and the situation in the last few years when the complaint has been all of the prevalence of hand-to-mouth buying and the unwillingness of business men to contract ahead for goods. In both periods, the telephone has performed a characteristic role for business. In 1920 merchants and manufacturers often combed the market with the telephone in order to provide themselves as promptly as possible with what they considered the necessary supplies of goods, personnel, or what not. More recently, when all the emphasis has been on keeping inventories down instead of laying in large inventories, the telephone has permitted business men to postpone until the last possible moment the ordering of new supplies, and there has been a really remarkable development of small-lot ordering by telephone. In both periods, the desire to eliminate risk prompted the use of the telephone as described, though from entirely dissimilar premises.

Let us turn now to a quite different type of influence of the telephone in market development. The phenomenon of industrial districts in our large cities is a common one. In New York, for example, Maiden Lane was formerly synonymous with the jewelry trade of New York City quite as much as Wall Street is with finance. Near Maiden Lane was "the Swamp," the hide and leather center. Newspaper row, the midtown garment center and the Worth Street cotton district of New York are other examples that readily come to mind of industrial centers that have grown up partly, though by no means wholly, because the leaders in the industry wanted to be near one another for competitive reasons. In some instances much of the industry has moved elsewhere because of inability to expand in a high-rent district or for other reasons, and where headquarters or selling agencies have remained in the original neighborhoods, the reason has probably been in part a matter of inertia, not governed to anything like the extent of former days by the necessity for any one firm being where the other sellers are, in order to be in the district to which the buyers must come. The telephone has eliminated much of this necessity, for while it is probably not yet possible to shop for diamonds or style goods over the telephone as satisfactorily as for staple cotton cloth or electrolytic copper, yet even in the case of a non-standard product, like high-grade jewelry, so much can be learned over the telephone that shopping even in this field and also in others requires, far less than it used to, concentration of all manufacturers or sellers, or selling agencies or traders, in one district. Thus the telephone has been one of the factors permitting decentralization of industries within cities, as well as within larger areas, as illustrated earlier by our Waterbury firm, while it has been performing the more important function of widening market areas.

The Telephone as a Salesman

So far in our consideration of the function of the telephone in the processes of distribution, we have dealt almost entirely with its usefulness in those cases where the buyer seeks out the seller at least as much as the seller seeks out the buyer. But in these days of high pressure competition in selling methods, with the seller seeking the buyer, particularly in "specialty" lines and non-standardized articles, the telephone has come to play an increasing part in selling activities. Ultimate consumers, retailers, jobbers, wholesalers, are all today being sold by telephone. Commercial departments of telephone companies have been peculiarly well equipped to give advice on the use of the telephone in selling, either as a routine matter or in specially planned sales campaigns. Just a few typical examples may be cited, merely to illustrate the different fields in which the telephone has been used as an aid to selling.

Beginning with raw materials, one of the interesting instances is the use of the telephone by cooperative growers' associations. Members, scattered over a wide territory, are able promptly to apprise association headquarters as frequently as the nature of their commodities requires, of the amount of produce they have ready for shipment, or the association can inform members of market conditions and advise as to timing of shipments. The association in turn can by telephone get promptly in touch with dealers, not merely to dispose of the produce on the best possible terms and at the earliest possible moment, compatible with satisfactory treatment, but to receive instructions as to where to ship goods and route cars, direct to consuming markets. Much wasteful transshipment is thus avoided. The telephone has in this manner been of inestimable assistance to such widely scattered producers as a group of farmers in disposing of perishable goods, in the marketing of which promptness, speed and economy are highly essential. Wholesalers of perishable produce similarly use the telephone in enabling them to sell and therefore to buy intelligently.

Coming to the case of manufacturers or dealers who have found it necessary to equip themselves with a group of salesmen who cover a given territory, we again find the telephone functioning to promote economy along with speed. It is so much quicker and cheaper to cover a territory by telephone than by personal visits, that the practice of solicitation of orders by telephone, particularly those of more or less routine character, is becoming an increasingly common practice, and has greatly augmented the efficiency of a sales force, either at headquarters or in the field. Such selling has probably been chiefly local or regional in character, either because the concern, being of moderate size, has sold only within a fairly restricted geographical area, or because a larger concern has had branch or district offices to take care of various parts of the country. It is clear though that, other things being equal, the more territory there is to be covered, the greater are the possibilities for economy of both time and money by the use of the telephone as compared with personal visits, and, therefore, the greater is the opportunity to meet the customer's specific needs just when and in the way he wants them met, at reasonable cost. A large manufacturing concern which sells nationally, principally to one type of retail dealer, and with customers numbered by the hundreds of thousands, formerly had its salesmen visit its customers two to four times a year. The sales cost was relatively high. This concern has districted the country for calling purposes and now calls its customers by telephone six or eight times a year, and in spite of this more intensive selling effort, the selling costs have been cut in three or four, even in what is really only the beginning of this experiment. Further, the manufacturer is naturally giving better service to its customers, while securing more mobile distribution for itself.

Order Tables; "Phoning for Food"

With wholesalers endeavoring increasingly to sell to retailers by telephone, growing use is also being made of the telephone in retail selling. Department stores in announcing sales are with increasing frequency encouraging in their advertisements the use of the telephone by customers, in order to save both the customers' and the salespeople's time, and even in a few cases allow a discount to cover a part or all of the expense of the telephone call. As a result of encouraging buying by telephone, certain concerns have installed order tables. Here a group of employees is used simply to take orders over the telephone or receive complaints about service, or, in some instances, to take the initiative in calling up customers more or less periodically. Public utilities as well as retail merchants are using these order tables.

A rather striking recent development has been the current campaign of the National Wholesale Grocers Association to encourage people to "phone for food." Selling is a time-consuming job for all concerned; and with the increasing importance of package and other trade-marked goods and the standardization and grading even of perishables, like fruit, it has been found that much selling time can be saved and that some costs can be substantially cut and the volume of business and size of the average individual sale increased by intelligent application of the "phone for food" idea. Wholesale grocers, incidentally, are endeavoring to sell increasingly by telephone to the retail grocers, whom they are encouraging to push the "phone for food" campaign. Thus the time of the retail grocer is saved in two ways,—in buying goods and in selling them.

In short, the telephone is found functioning at every stage of distribution, as it does in the various stages of production, accelerating processes and thus saving time, economizing effort, reducing risks, and generally cutting costs, in a field where there is much room for cost-cutting. Granted that it functions the more readily, the more standardized the product which is being distributed or merchandised, it is by no means of use solely in the case of standardized products. In so far as it is indirectly encouraging standardization, it is contributing not only to the facilitation of distribution but to a form of elimination of waste, which is just now especially popular.

The telephone has become an increasingly useful handmaiden of business, as industry and trade have been able to avail themselves more and more of the opportunities afforded by the telephone for the acceleration and intensification of their processes. By aiding in the more efficient and economical conduct of business, the telephone has increased the productiveness of industry and thus been one of the important factors which have raised the standard of living in this country to the highest level in history and the highest level in the world today. This the telephone has done while it has been performing its social functions in binding communities more closely together and increasing human happiness by facilitating human contacts. All that has been attempted in this article is to draw a general picture of the telephone as an economic instrument. The few specific instances that have been given of the functioning of the telephone have been only illustrative samples and by no means cover the field even of its present usefulness. The telephone seems destined in the future to make far greater contributions than it has in the past to the economic development of the country.

Carrier Telephone System Installed Between Sydney and Melbourne

By FRANCIS A. HUBBARD

Assistant Chief Engineer, International Standard Electric Corporation

THE inauguration of a carrier telephone system on September 10, 1925, between Sydney and Melbourne, marks an important step in Australia's progress towards improved telephone service. Australia, because of the large area and uniformity of language, offers an especially fertile field for the application of the latest improvements in long distance telephony and telegraphy.

Sydney and Melbourne are the principal cities of the Commonwealth. The former, in the state of New South Wales, has a population of just over one million, while Melbourne, the chief city of Victoria, is a close second with approximately 900,000. From a telephone standpoint they compare favorably with most leading cities in Europe, each of them showing well over seven telephone stations per hundred population. Together they contain about one-half of all the telephones in Australia.

There is naturally a very considerable community of interest between two cities of this size, located some 450 miles apart in an air line,—both seaports, both leaders in the commercial and business life of the Commonwealth. This community of interest, together with the very fair degree of telephone development, inevitably means a demand for telephone service. Until recently, however, only two telephone circuits have been in service between the cities; and they have been seriously congested, with delays frequently of more than an hour in the busy period. Such a condition always results in the deflection of a considerable amount of potential telephone traffic, of a less urgent character, into the channels of the telegraph or post. The demand for additional telephone facilities was urgent, and since the 150% increase in facilities calls are completed on the average within about 17 minutes.

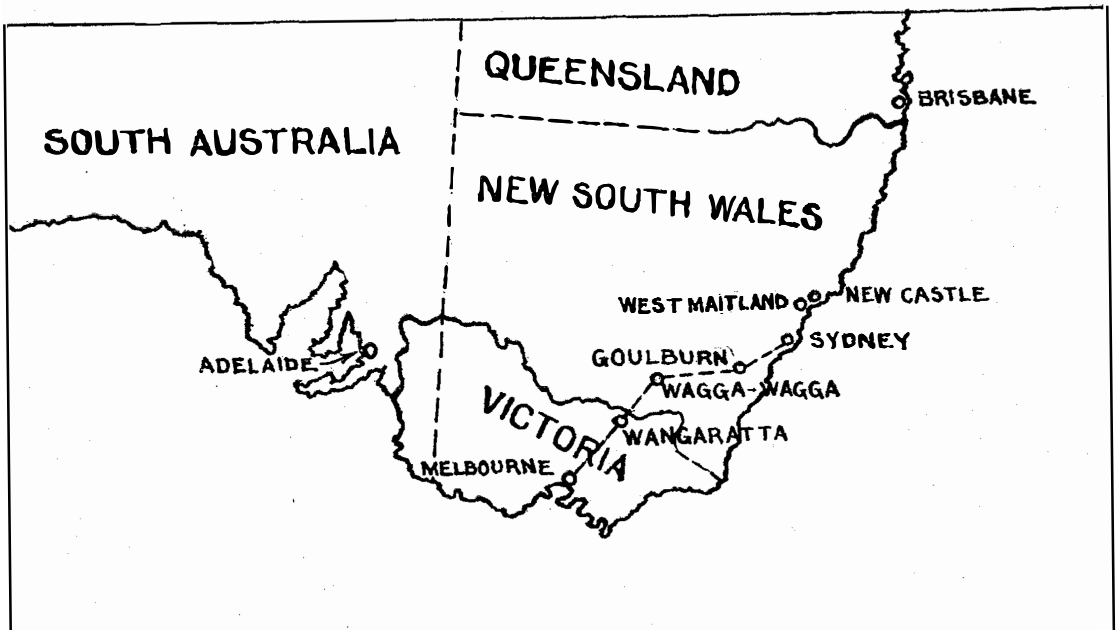
The new carrier system was installed on an existing 600 pounds per mile copper (4.92 mm. diameter) circuit between the two cities, which are nearly 600 miles (967 kilometers) apart by the circuit route, and provides three telephone channels. The installation of the new system does not interfere with the operation of composited duplex telegraph over each wire of the circuit.

The route followed is shown on the map, Figure 1. Due to the relatively high attenuation to the carrier frequencies, three repeaters are required to give the excellent net efficiency of about 9 TU between Sydney and Melbourne. These are located as shown in Figure 1 at Goulburn, Wagga Wagga, and Wangaratta.

The system was furnished by Standard Telephones and Cables (Australasia), Limited, and is of a type which has been used extensively in the United States by the Bell System. The transmission of the voice currents is accomplished by means of a high frequency carrier current which is produced by a vacuum tube oscillator at the transmitting end. This carrier is modulated through suitable means by the voice currents. The modulated carrier, as is well known, contains the original carrier frequency and two side bands. In the Sydney-Melbourne system the carrier and one side band are transmitted over the line. At the receiving end the received high frequency current is demodulated and the original voice current is obtained.

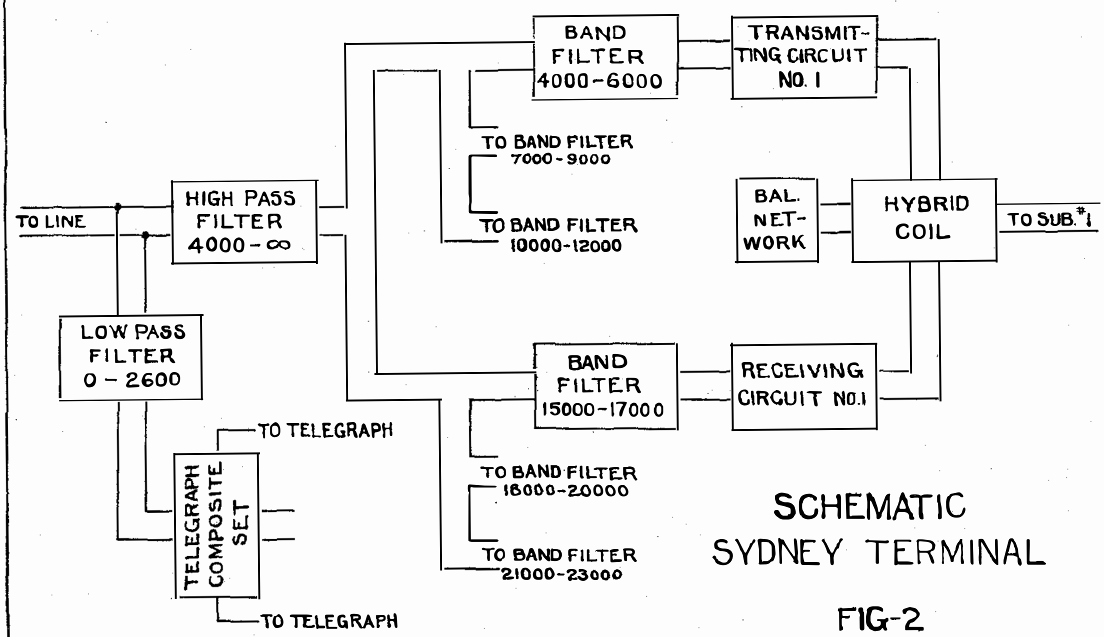
In order to transmit several telephone conversations simultaneously different carrier frequencies must be used for the several channels. The high frequency currents of each channel must be separated from the others at both the receiving and transmitting ends by suitable selective circuits, although on the line all frequencies are, of course, present in the line current.

Various methods of operating simultaneous carrier telephone channels are available. One of the first systems used commercially employed the same frequency for transmission in both directions for a given channel; the transmitted and received currents being separated by means of a hybrid coil and line balancing network in a manner similar to that used in voice frequency two-wire repeaters. Due to the difficulties experienced in obtaining sufficient balance at the high frequencies under operating conditions, and because of later refinements in the design of selective filters, the above system



CARRIER TELEPHONE ROUTES

FIG-1



SCHEMATIC
SYDNEY TERMINAL

FIG-2

has been replaced by the present scheme in which different frequencies are used for transmission and reception in each channel, the two circuits being separated only by the band filters.

In order, therefore, to obtain three two-way channels as used in the Sydney-Melbourne system, six carriers are required and the selective circuits are arranged to transmit these with one side band each, the second side band being suppressed in each case. Figure 2 shows a schematic of the Sydney terminal, and Figure 6 is a photograph of the equipment. Figure 3 indicates diagrammatically the allocation of the frequencies. Each side band is about 2,000 cycles in width so that voice frequencies as high as this value are transmitted. For transmission from Sydney to Melbourne the three carriers employed are 6,000 cycles, 9,000 cycles and 12,000 cycles. The lower side bands together with each carrier are transmitted. For transmission from Melbourne to Sydney the three carriers are 15,000 cycles, 18,000 cycles and 21,000 cycles; the upper side band in this case being transmitted with each carrier. The use of the lower side bands in one direction and the upper side bands in the opposite direction minimizes crosstalk because of the wider frequency separation between the transmitting and receiving groups.

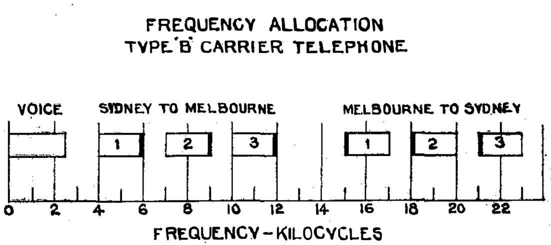


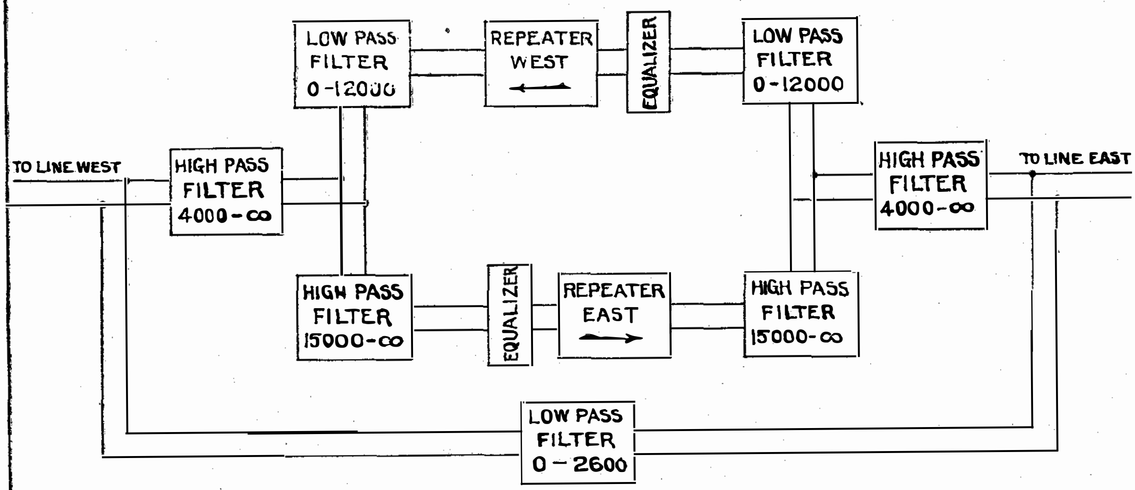
FIG-3

Referring to Figure 2, it is seen that at the voice frequency end the transmitting and receiving currents are separated by a hybrid coil and balancing network in each of the three circuits. Outgoing voice currents from a subscriber pass to the associated transmitting equipment where the high frequency carrier current is modulated by the voice current. From the transmitting equipment the modulated carrier is impressed on a band filter which passes only the carrier and the lower side band in the Sydney terminal (the upper side band in the Melbourne terminal). As shown in the figure, the three transmitting band filters and the three receiving band filters are all connected in series. The impedance of each is very small at frequencies other than those which each is designed to transmit and, therefore, only small losses are introduced in each channel by the other filters. The six band filters are connected to a high pass filter, which connects to the line and passes all frequencies above the lowest one in the lowest side band, about 4,000 cycles. This high pass filter is used to eliminate the normal voice frequencies from the carrier circuits. The normal voice frequency and D.C. telegraph channels are bridged across the line through a low pass filter which eliminates the carrier currents from these channels and transmits only frequencies up to about 2,600 cycles. As previously stated, the system does not interfere with the operation on either wire of grounded composited telegraph, which is connected to the voice frequency channel in the usual manner by means of a composite set.

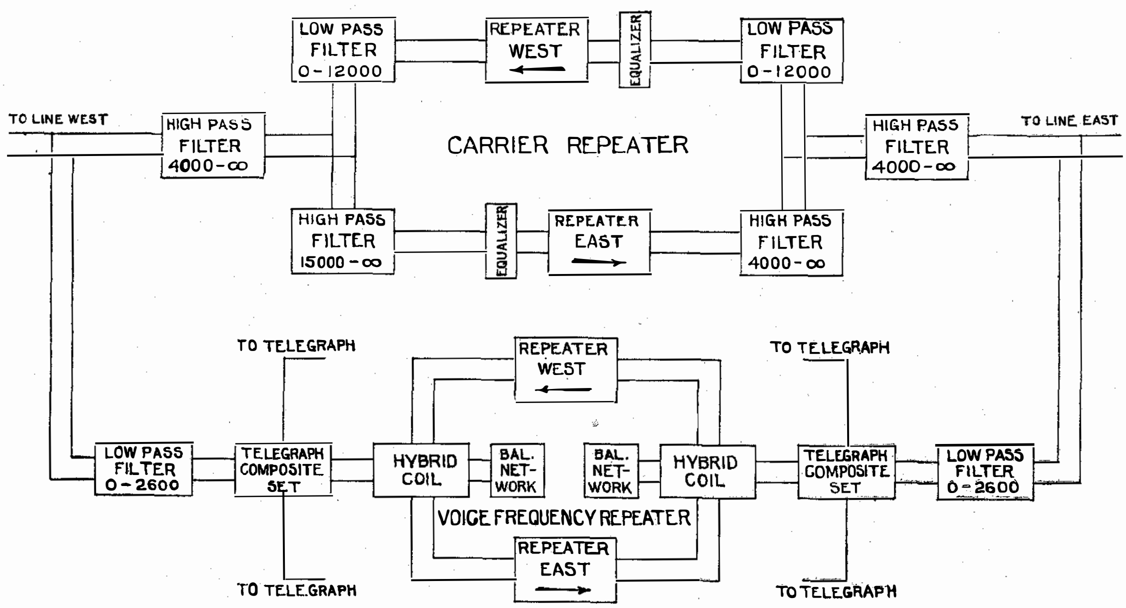
After the receiving group of carriers and side bands are transmitted through the high pass filter, they are impressed on the band pass series filters which separate the respective carriers and upper side bands into the three receiving circuits where they are demodulated and amplified. The resultant amplified voice current is transmitted through a hybrid coil to the local subscriber's circuit.

At the Melbourne terminal the arrangement is similar except that the band pass filters are interchanged in the transmitting and receiving branches to provide for transmission on the higher group of frequencies and reception on the lower group.

The terminal equipment which is panel mounted on angle iron frames is shown in Figures 6 and 7. Except for the line filters, one complete terminal equipment is mounted on three bays. In addition to the three channel units containing the oscillator and modulator tubes, as well as the signaling rectifier, demodulator and amplifier tubes, these bays contain the power supply equipment, testing equipment and controls, the signaling apparatus, transmitting and receiving band filters and mis-



SCHEMATIC CARRIER REPEATER
WANGARATTA AND GOULBURN
FIG-4



SCHEMATIC OF CARRIER REPEATER
AND
VOICE FREQUENCY REPEATER
WAGGA WAGGA
FIG-5

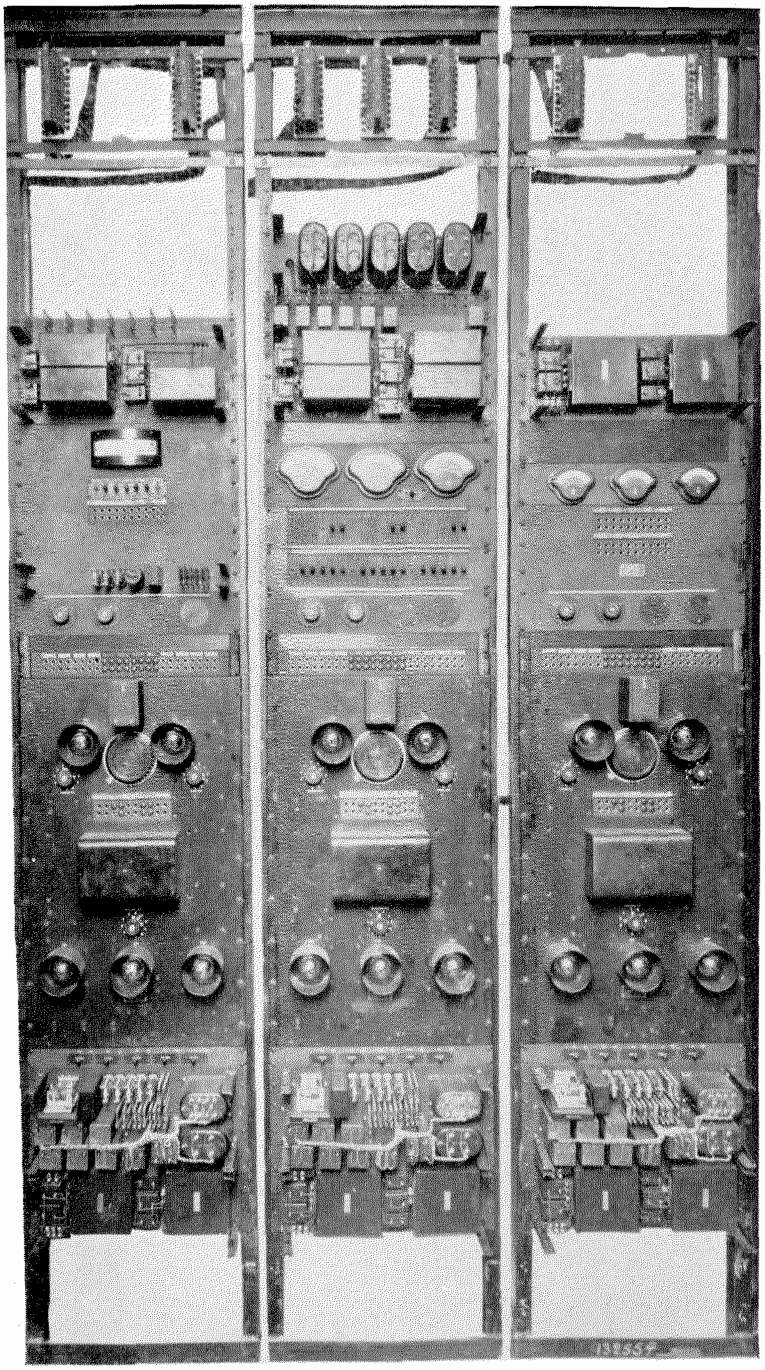


Figure 6—Terminal Equipment Type B Carrier Telephone—Front View

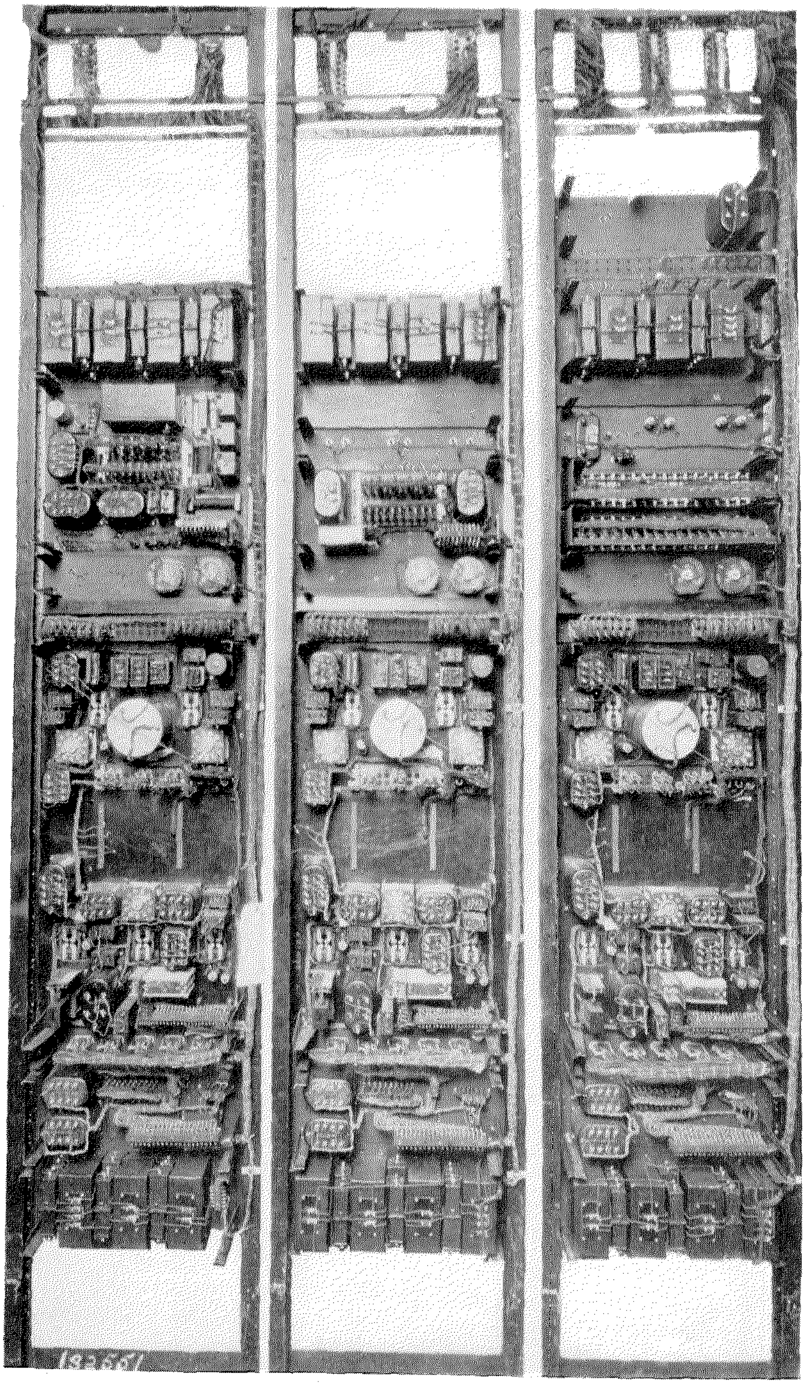


Figure 7—Terminal Equipment Type B Carrier Telephone—Rear View

cellaneous keys and jacks to aid in operation and maintenance of the system.

It has been stated that three carrier repeaters are required in the circuit. Figure 4 shows schematically the arrangement of filters and amplifiers used at Wangaratta and Goulburn.

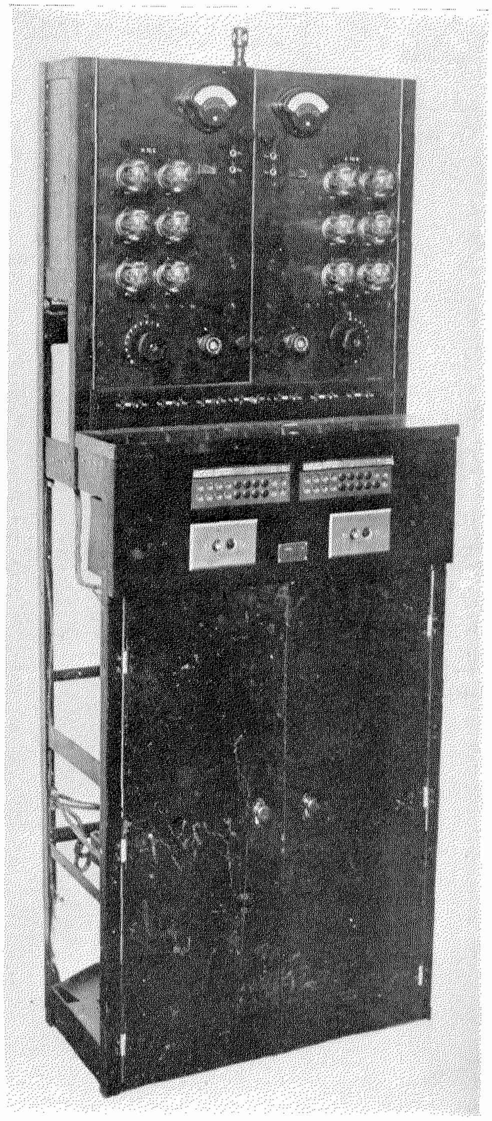


Figure 8—Repeater Type B Carrier Telephone

Figure 8 is a photograph of the equipment. Since a voice frequency repeater is also necessary at Wagga Wagga the circuit is more complicated and is shown in Figure 5. The carrier repeaters used at these points are designed to amplify by means of a single amplifying unit all frequencies in each group without excessive crosstalk due to demodulation between channels, an arrangement which obviously, is much simpler than the use of band filters and separate amplifying elements for each channel. One important feature of these carrier repeaters is the high frequency equalizer in the input of the repeater elements. This equalizer compensates for the large difference in the attenuation of the line over the frequency range of 4,000 to 12,000 cycles in one direction and 15,000 to 23,000 cycles in the other direction, and greatly improves the overall operating characteristics on lines of such length as require repeaters.

Referring to Figure 8, the carrier repeaters are unit floor mounted and contain all the equipment except the line filters. At the Wagga Wagga office, on account of the use at this point of a voice frequency repeater, an additional low pass line filter together with filter balancing equipment for the voice repeater balancing network are required.

The power requirements for both the terminal equipments and the repeaters consist of 24 volts for supplying the filament current to the vacuum tubes and 130 volts for furnishing the space current. The current in all cases is furnished by storage batteries, suitable charging equipment being required for maintaining the batteries.

Arrangements must, of course, be provided for signaling between terminals. As already mentioned the carrier system is arranged so that either 20 cycle or 135 cycle ringing current can be used over the line. The Sydney-Melbourne circuits, however, use 20 cycles. At the receiving end an auxiliary rectifier tube, above referred to, is associated with the demodulator of each channel in such a manner that the incoming carrier current produces in the output circuit of this rectifier a direct current sufficient to maintain a relay in its operated position. When an operator signals, the ordinary 20 cycle ringing current is received at the sending carrier terminal. This operates a relay which disconnects the source of carrier current from the modulator, thereby stopping its transmission over the line. As a result the relay at the distant terminal controlled by the rectified current falls back, causing an ordinary 20 cycle ringing current to be sent out over the connecting line associated with that particular channel.

Although this system was installed to give three telephone channels on two wires, two such equipments may be used for six channels on a four-wire basis under suitable line conditions. In this case all six carriers would be used for transmission in each direction. Such a system has the advantage over two three-channel systems on a two-wire basis in that crosstalk requirements are not so severe since crosstalk appears as side tone. The four-wire system therefore, makes possible satisfactory results with less carefully transposed lines.

In order to assure successful results, Mr. J. S. Jammer of the Bell Telephone Laboratories, Inc., New York, where the equipment was designed, went to Australia early in 1925 in order to supervise the preliminary work on the lines and the installation and testing of the carrier terminals and repeaters. The work on the lines connecting Sydney and Melbourne included a considerable amount of new transpositions and the elimination of irregularities which would interfere with the most efficient operation of the system. The actual work of installation was done by the Australian Administration under Mr. Jammer's guidance and the results being obtained indicate both the thoroughness of that supervision and the skill of the Administration officers and staff.

It is interesting to note the flexibility of this carrier equipment. At the time the lines were being overhauled both circuits were put into suitable condition for carrier working, although at present only one is so used. Not long after the carrier was put in service a fault occurred on the circuit, making the satisfactory operation of the carrier over this circuit impossible until the fault was cleared. The second circuit, however, remained in good condition. The carrier equipment was, therefore, switched with little delay to the good circuit on which it functioned satisfactorily while the first circuit was being cleared.

The official opening of the system was inaugurated by four simultaneous conversations between officials of the two cities. At the same time telegraph messages were interchanged over the telegraph facilities on the same pair of wires which furnish the three-channel carrier and the one normal voice frequency channel. Immediately after the official opening the new facilities were put into commercial service. The satisfactory results being obtained are evidenced by the fact that traffic increased some 30% within a very short time.

Wire Telephone Communication in Theory and Practice†

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Summary. The object of this paper is to present in non-mathematical terms the elements of transmission of speech over wires. The nature of language and the conditions for intelligible communication by speech are briefly considered. A short discussion is given of the requirements of a telephone transmission system together with the effects and functions of the several parts of such a system. Loading and the application of telephone repeaters are discussed. Attention is called to the causes of interference resulting in noise on telephone circuits and means for minimizing these effects are outlined. Finally, fundamental plans and the establishment of economical service and the testing methods evolved to assure the continuance of good service are reviewed. The paper is, in general, a summary of literature already published, but in scattered form.

The Nature of Audible Speech*

In any paper dealing with the transmission of the spoken word to distant points by means of electrical systems, it is essential to consider to some extent the nature of speech and the *modus operandi* of hearing.

Speech, and all sounds for that matter, are transmitted by vibrations of matter of a more or less complicated nature, ranging from simple harmonic and complex vibrations to aperiodic ones which are difficult of analysis. The vibrations which the human voice is capable of producing range from those of about 60 vibrations a second to over 6000 a second. These sounds may be periodical, each sound containing a number of frequencies—a fundamental and overtones, but are often a combination of such tones with aperiodic ones. The energy of the sounds varies, of course, with the speaker and the frequency. Tests have shown that for average speech the maximum energy occurs at about 200 cycles. The energy is necessarily very small, and it may be of passing interest to note that calculations have shown that if a million people talked steadily for an hour and a half and the voice vibrations were converted into heat, only enough heat would be produced to make one cup of tea.[1] Furthermore, most of this energy is contained in the vowel sounds, although the consonants are of great importance in making speech intelligible. The important frequency range of the vowel sounds lies below 3000 cycles, whereas the consonants are in general the higher frequencies within the voice range and weak in energy.

Hearing consists in the translation of the air vibrations set up by the voice, or other source, into the sensation which we call sound. The scope of this paper does not permit a discussion of the theories of hearing, but must be confined to the observed results.

Experimentation has shown that the average ear records impinging air vibrations as sound within a limited range of loudness and frequency of vibration. That is, vibrations become inaudible when their intensity is less than some value, and register as feeling rather than sound when the intensity is too great. Below and above certain frequencies, air vibrations are not recorded by the ear as sound. Above the upper limit no sensation is experienced, whereas below the frequencies definitely sensed as sound it becomes difficult to distinguish between hearing and feeling.

In Figure 1 is given a plot of auditory sensation for the average human ear.[25] The lower curve indicates the ear sensitivity for sounds of different pitches and was obtained by measuring at each particular frequency the intensity of the least sound which could be heard. This curve is known as the minimum audibility curve. The upper one was obtained by measuring the intensity at each frequency when the sensation just ceased to be hearing and registered as feeling. Accurate observations near the upper and lower frequencies were difficult to make, hence the curves were extended by extrapolation. From a consideration of these data it is reasonable to define the frequency limits of normal hearing as lying between 20 and 20,000 cycles.

The study of hearing has brought out a number of very interesting phenomena. For instance, it has been observed that for very loud sounds, frequencies not physically present in the source are heard. The introduction of another pure tone causes reactions between the so-called subjective tones. Also, it has been found that a tone

* The discussion of the nature of language is based largely on R. L. Jones' paper "The Nature of Language." See *Bibliography*, Reference 1.

† Presented at the Annual Meeting of the Telegraph and Telephone Section of the American Railway Association, New Orleans, La., October, 1925.

of one frequency may mask or obscure a tone which is weaker but higher in frequency. On the other hand, high tones, even though loud, have very little effect on lower ones. Thus it is seen that under certain conditions the normal ear itself may be a source of distortion of the received sounds. Defective ears most frequently cause distortion of sounds within the normal range by not responding to the normal frequency range, as well as by requiring greater intensity to produce an audible sound over the audible frequency range. There appears to be no shift in the upper or feeling curve from that of normal hearing.

Having briefly discussed some of the factors involved in speech and hearing, we must next turn our attention to the interpretation of speech. A technique has been developed whereby it is possible to measure quantitatively the accuracy with which speech is transmitted to the normal ear. Such a technique includes the translation of so-called articulation into terms of intelligibility, or the latter may be measured directly. Naturalness of speech is a factor involved in transmission, but its effect on intelligibility is still not definitely determined. The per cent intelligibility obtained from a given system of transmission is reduced by the introduction of disturbing sounds. The amount by which such disturbing sounds decrease the intelligibility is subject to quantitative measurement.

Distortion of the original sounds by the transmission system is often the reason for decreased intelligibility. Such distortion may be caused either by the transmission of different frequencies with different efficiencies, or by the introduction of frequencies not present in the original sound. The first type of distortion is known as frequency distortion and the second as non-linear distortion. In telephone transmission systems the former is caused by the efficiency characteristics of the apparatus and connecting lines, and by the resonance response of the transmitters and receivers. The latter may be introduced by transmitters or by improperly operated repeaters.

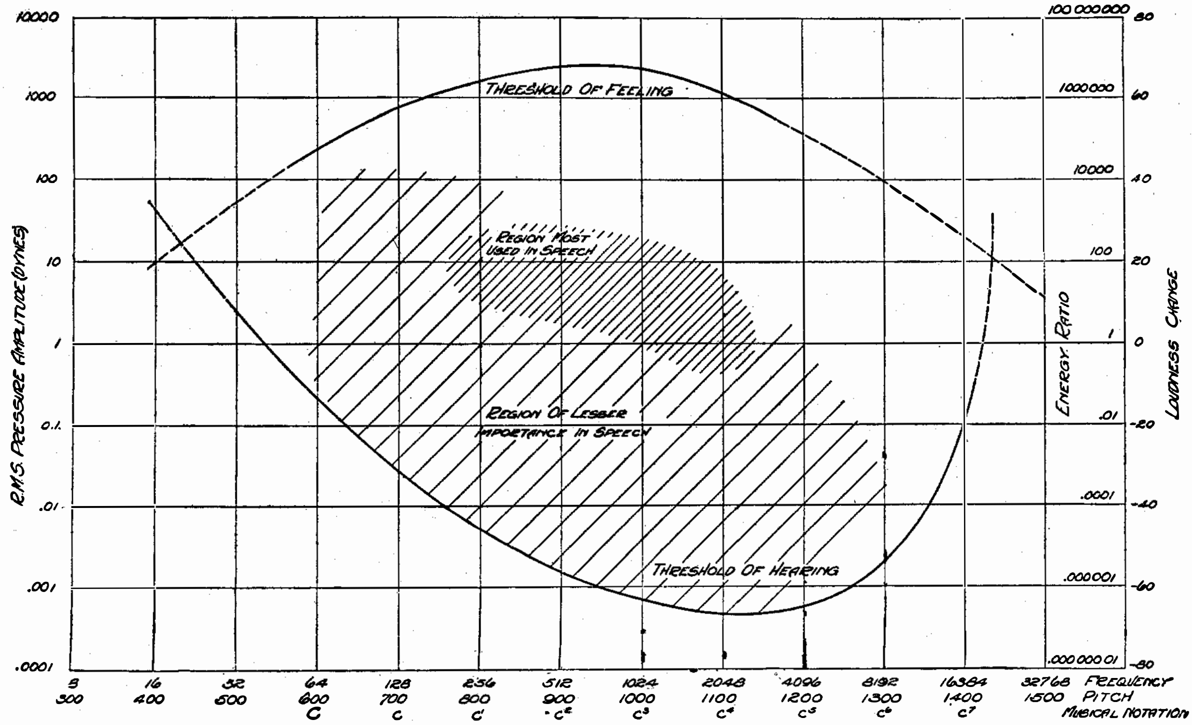


Figure 1

Experiments have shown that for intelligible transmission of speech it is not necessary to transmit the full range of frequencies in the voice, namely, 60—6000 cycles. It has been found that with a range of 300 to 2000 cycles, reproduction of speech is obtained which can be easily understood. Where the naturalness is of great importance, as in broadcasting, equal attenuation from 200 to at least 3000 cycles is considered necessary for speech transmission, and a range of at least 100 to 5000 for music.[17]

Very interesting experiments have been carried out on a system which is as nearly free from distortion as can be built.[35] Into this circuit were introduced electrical filters which have the characteristic of transmitting currents of certain frequencies and practically eliminating all others. It was therefore possible to eliminate from the voice currents being transmitted over this system, frequencies above or below certain predetermined values, thus transmitting only a limited band of the frequencies present in the voice sounds. In this manner the effect on articulation of the elimination of certain frequencies has been determined.

Figure 2 shows the results obtained by using low-pass and high-pass filters in the high quality circuit with no noise. To quote:[1] "The ordinates show the per cent of syllables called which were correctly recorded at the receiving end. The abscissas represent the marginal or cut-off frequency of the filter. Looking at the curve for the low-pass filter, marked Articulation L, the point (1000,40) indicates that an articulation of forty per cent is obtained when the system transmits only frequencies up to 1000 cycles. Looking at the curve for the high-pass filters, marked Articulation H, the point (1000,86) indicates an articulation of eighty-six per cent for a system transmitting only frequencies above 1000 cycles. The dotted curves show the per cent of the total energy in speech transmitted through filters of the two types having cut-off frequencies corresponding to the abscissas. Sixty per cent is lost if all the energy below 500 cycles is eliminated, but only two per cent of the articulation. The suppression of the frequencies above 1500 cycles reduces the articulation by thirty-five per cent but only ten per cent of the energy lies in this region. The suppression of all frequencies below 1000 cycles has no greater effect than the suppression of the frequencies above 3000 cycles. This is quite contrary to the popular notion of the characteristics of speech. The mean frequency from the standpoint of articulation is about 1550 cycles. An articulation of sixty-five per cent is obtained when either the frequencies below or those above that point are used. The speech quality sounds very different in the two

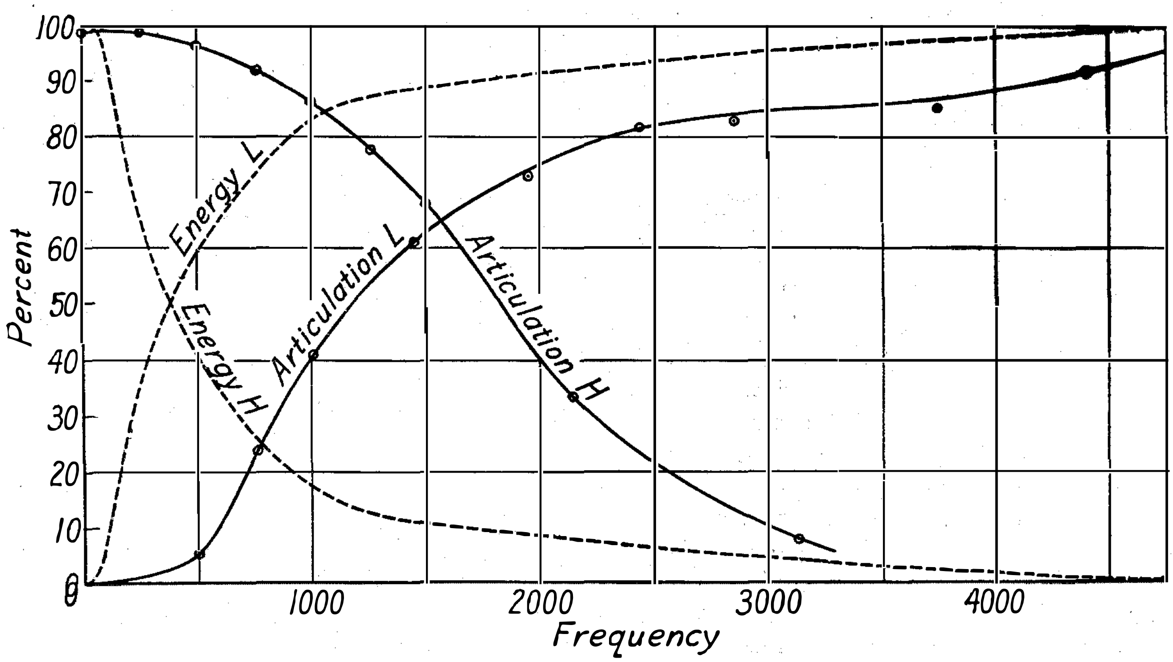


Figure 2—Effect upon the Articulation and the Energy of Speech of Eliminating Certain Frequency Regions

cases, however, in the one being low and dull, and in the other high and shrill.

"It should be borne in mind that naturalness of reproduction, as well as articulation, is an important element of understandable and satisfactory spoken communication. As has been pointed out above, although the fundamental chord tones and harmonics lying below 500 cycles carry most of the speech energy, they contribute little to the articulation. It has been observed that naturalness of reproduction is greatly affected, depending upon whether or not these low frequency tones are preserved. While it might be concluded from the articulation data then, that frequencies in the lower part of the speech range are unimportant, a fuller consideration justly attributes an added measure of importance on account of naturalness. The naturalness of speech quality is a characteristic calling for considerable further investigation."*

The intelligibility of transmitted speech depends upon the accuracy with which the original sounds are reproduced as sound waves at the receiver, and also in a rather complicated manner on the loudness of these sounds, not only relatively to disturbing sounds, but also in absolute value, on account of the ear characteristics already discussed. In a complete study of a transmission system, therefore, all of these factors must be considered. In many cases, however, the volume or loudness of received speech is the factor of principal interest. This is the case in planning a telephone system, for with the disturbing noises due to inductive interference, etc., kept to a minimum, and the distortion held within commercial limits, the volume is the remaining variable under control. Some method of designating the relative volume efficiencies of systems as a whole as well as of their individual parts is desirable. In other words, some unit of measure for the variation in loudness of speech should be available.

The Transmission Unit and the Reference System

In the Bell System it has been found advisable to adopt (and it is hoped this unit will become universal)[26, 27] a unit known as the Transmission Unit (*TU*) which represents a change in the energy of sound about equal to the minimum change that an average ear is capable of detecting. That is, if a transmission system is reproducing speech of a certain loudness and some change is made in the system which decreases the loudness by a just noticeable amount, a loss of about one *TU* has been introduced into the system. If a second loss of one *TU* is introduced, the third volume will be just noticeably less than the second, but the third volume of sound which is two *TU* less than the original will be clearly less, if the total loss is suddenly eliminated. In other words, a change in loudness of a given number of *TU* will cause the same relative volume change each time such a loss is introduced. It is analogous to the more familiar effect of change in musical pitch in which doubling the frequency of vibration causes the pitch to rise by an amount known as an octave. Specifically, one *TU* is a change of power by a ratio of 1.259 logarithmically expressed.†

The principal function of a telephone system is to enable its subscribers to carry on satisfactory conversation. Telephone engineers are confronted with the need of some method of rating the performance of telephone circuits for the comparison with one another and for the maintenance of certain grades of transmission. One method of rating transmission which has been widely used is the comparison of telephone systems on the basis of loudness or volume of speech in the receiver at the receiving end. The particular arrangement which was employed for this purpose in the Bell System‡ is shown in Figure 3. The amount of standard cable in this circuit is adjusted until the loudness of speech in the listener's receiver is equal to that in the listener's receiver of the system under comparison. The number of miles of standard cable required in the reference system to produce this equality is known as the equivalent of the system under test. The same speech source is used to actuate

* Based on "The Nature of Speech and its Interpretation." H. Fletcher. Bell Tech. Jour., July 1922.

† The *TU* is a logarithmic measure of the power ratio and is numerically equal to log. $10^{0.1}$. The number of *TU* corresponding to any power ratio is given by $N_{TU} = 10 \log._{10} \frac{P_1}{P_2}$.

‡ This discussion of the Reference System is based largely on L. J. Sivian's paper "A Telephone Transmission Reference System"—Electrical Communication, October, 1924. See Reference 32.

alternately the transmitting ends of the two systems.

The sound outputs of a great many commercial systems differ from each other and from this reference system principally as regards loudness. In such cases a loudness comparison such as described above gives an adequate criterion for rating the circuits. It may further be established by actual voice-ear tests that all circuits of this type give satisfactory transmission if maintained between certain two equivalents. For circuits of similar types it is, therefore, readily possible to establish certain grades of transmission and to see that the circuits are maintained within these limits.

Researches during the last few years have developed techniques, already referred to, for establishing the quality of transmission in more comprehensive terms than that of volume. The extensive use of telephone circuits in broadcasting has necessitated more consideration of the distortionless transmission of speech and music than is required by commercial circuits. Furthermore, recent developments have made possible the production of apparatus and circuits which are capable of transmitting speech with much less distortion than was formerly the case. For these reasons the reference system just described has been limited in its usefulness, and consideration has been given to the development of a reference system which can be used as one for the measurement of quality standards in the broader sense.[27, 28] A preliminary model has been built which consists of suitable transmitting and receiving equipment with an adjustable network calibrated in TU. The whole equipment is to be as nearly distortionless as possible. In order to tie this new reference system in with the old one, the former will be adjusted to have the same volume of reproduction with 24 TU in the reference line as that of the old system with 24 miles of standard cable.

For practical uses it is expected that auxiliary reference systems having characteristics more comparable with commercial circuits will be desired. These will be calibrated in TU against the primary or a secondary reference system of the distortionless type.

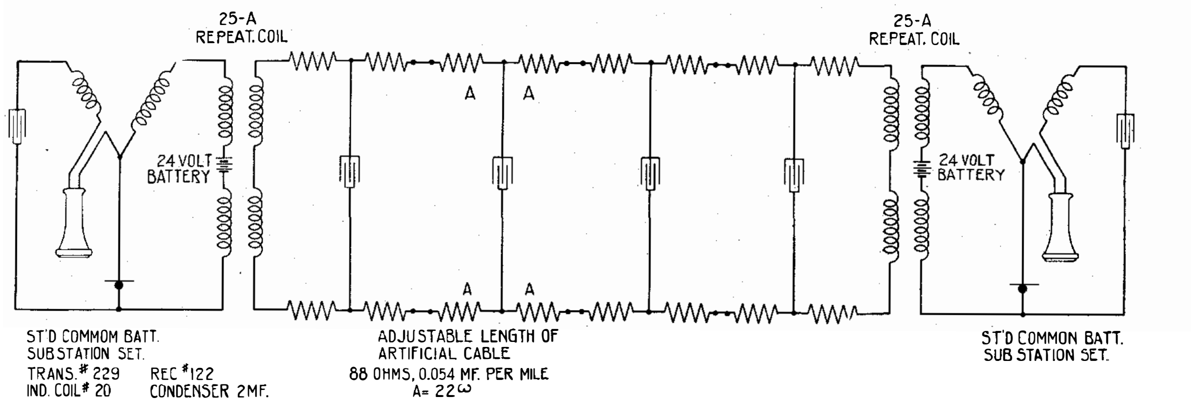


Figure 3—Artificial Cable Reference System

Elements of Telephone Transmission at Speech Frequencies *

A telephone system should supply adequate facilities for enabling persons more or less remote from one another to converse readily. In such a system the first requisite is, of course, suitable signaling and operating facilities which will connect the telephone sets of the parties desiring to communicate. These features are not, however, within the scope of this paper. When a connection is established, however, the transmission problem becomes of primary importance for the system must be capable of transmitting intelligible speech. It is well to bear in mind also the economic aspects of the case. A system which transmits speech with very slight distortion is expensive, and conversely a system which is inexpensive will not, in general, transmit speech as clearly. It is necessary, therefore, that there

* A considerable part of this subject has been taken from "Transmission Circuits for Telephonic Communication" by K. S. Johnson, Pub. Van Nostrand Company, New York, and "Telephone Transformers" by W. L. Casper, A. I. E. E. Jour., March 1924.

shall be working rules and methods by which it shall be determined in each particular case just how good, and, therefore, how expensive the circuits used for any given class of service shall be.

Some discussion has already been given to the rating of the overall performance of telephone systems at voice frequencies. In order to build up reference systems or commercial systems, it is necessary, in addition to being able to compare the overall performances, to analyze them and determine the effect of each part on the final results. Methods have been devised to accomplish this with considerable facility.[19] Such means familiar to the telephone transmission engineer involve not only tests and measurements of many kinds,[20, 21] but considerable mathematical analysis which it is not proposed to enter into here. The general characteristics and *modus operandi* of the constituent parts, as well as the proper means for associating them, will be briefly discussed, however.

Before entering into a detailed consideration, it may be worth while to note some of the characteristics and requirements of a telephone system in counter distinction to those of power transmission systems, which latter have in the past been perhaps more generally familiar to electrical engineers.

The transmission of power is, of course, at relatively high voltages and at a single rather low frequency. The power generator is designed for the particular frequency and voltage being transmitted. The power line itself must have a high efficiency, and, in general, the power delivered to the load or the absorber is not less than seventy-five per cent of the original power delivered by the generator. The power drawn from the generator by the power system is determined primarily by the character of the load, which is designed to draw from the line the minimum power necessary for doing the required work.

In contrast to the above, the telephone system, as previously pointed out, must transmit a considerable band of relatively high frequencies with uniform efficiency. Due to the high losses in telephone lines, the amount of power drawn from the generator (the transmitter) is nearly independent of the load. The efficiency of the telephone system in long connections may be less than 0.1% without making conversation difficult. Telephone receiving apparatus or the absorbers are, with a few exceptions, designed to draw the maximum power possible from the line. In contrast to the high power in the power field, a transmitter may deliver approximately 0.004 watts to the telephone system, of this less than four millionths of a watt may eventually reach the receiver. The receiving equipment of the telephone plant instead of operating on a rather small variation of power is required to function with extreme differences. The received current may be as high as three thousandths of an ampere or as low as one ten-thousandth of an ampere, a variation of 900 times in power.

One piece of equipment which is of great importance in power as well as telephone engineering is the transformer. Of course the requirements of the types used in these two fields are very different. Instead of handling kilowatts at very high voltages, the telephone transformer handles microwatts. Power transformers are generally operated at a single frequency and under a limited voltage variation. On the other hand, telephone transformers in common with other telephone equipment, as previously mentioned, must operate under a wide variety of conditions of both voltage and frequency. Telephone transformers[2] were first used in the transmission of voice frequency current up to about 2500 cycles, but with the advent of carrier current and radio systems types have been developed capable of use with frequencies very much higher.[13, 14]

There are many special requirements imposed on telephone transformers, among which, in addition to the frequency requirements just mentioned, are high efficiency to alternating current when superposed D.C. is flowing through the coil; a high degree of impedance balance between the windings in order to prevent unbalancing the circuit with consequent troubles from noise and crosstalk. Of course not all of these requirements are placed on all transformers in the same way.

Transformers may take numerous forms, such as induction coils used in subscribers' and operators' sets, the repeating coils of cord circuits and phantom circuits, or the input and output coils of telephone repeaters. In certain cases they may be used principally to isolate metallically one part of a circuit from another, as in certain types of cord circuits.

It is possible to show that maximum power will be transferred from one circuit to another if the impedances* of these circuits are equal in magnitude but of opposite phase,† that is, if the resistances are equal and the reactances annul each other. If the reactances are separately annulled but the resistances are not equal, the greatest transfer of power will be obtained if an ideal transformer having a turns ratio equal to the square root of the ratio of the resistances is inserted. Ordinarily the reactances cannot be annulled over the entire frequency range of interest and no attempt is, therefore, made to do this. Under these conditions, the most efficient method of connecting the circuits is by means of an ideal transformer having the number of turns on the windings in the ratio of the square root of absolute value of the two impedances.

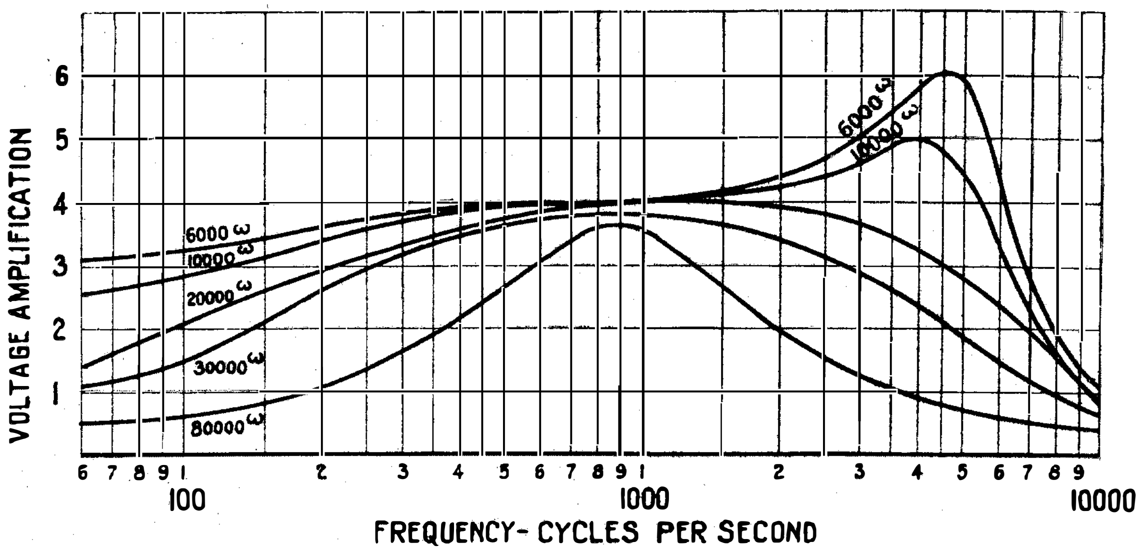


Figure 4—Voltage Amplification Characteristics of an Input Transformer of Impedance Ratio 1:16 Operating from Various Resistances into a 216-A Vacuum Tube

Figure 4 gives typical curves for the voltage amplification ratio of a certain type of transformer[2] when operating between various resistances and the input of a 216-A vacuum tube. These curves illustrate the effect of the circuit impedances on the efficiency-frequency curve.

* The impedance of a circuit is equal to the ratio of the voltage impressed to the current flowing in that circuit.

† The phase angle of an impedance is the angle between the resistance component and the total impedance, and is given by tan.$^{-1}\frac{X}{R}$ where X is the reactance and R the resistance component. The reactance is considered positive if inductive and negative if made up of capacitance.

Similar curves have been obtained by direct measurement showing the efficiency characteristics of transformers under many operating conditions. Methods have been developed which make possible the analysis of the characteristics of the transformers in such a manner that the design of other transformers for different circuit conditions is greatly facilitated.

Cord Circuits

Cord circuits, or the corresponding circuits in machine switching systems, are the assembly of equipment at the telephone office necessary for connecting two telephone lines when communication between two parties is desired. These circuits, of course, take many forms depending upon the nature of the connected lines, etc. In general, they have three principal functions: namely, (1) To furnish signaling means at the telephone office by which the operator may be recalled or the lines are disconnected when the parties are through talking; (2) To give an efficient transmission connection between the lines; (3) In systems in which direct current necessary for the satisfactory operation of the transmitters is supplied from the central office (called a common battery central office), to supply such current over one or both lines to the subscribers' sets. It is not within the scope of this paper to describe signaling features, so attention will be directed to the second and third functions of the cord circuits.

Three typical cord circuits are shown schematically in Figure 5. Each type has its particular field of use.

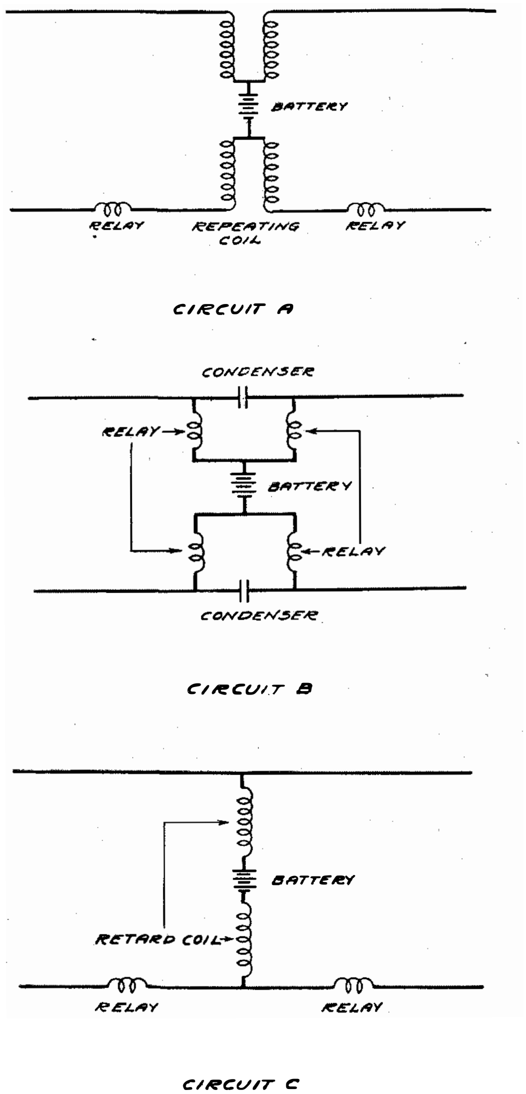


Figure 5—Types of Cord Circuits

The circuit shown as "A" is that used quite generally in manual offices for connecting two subscribers' lines in the same office. It will be observed that a transformer is employed which has the same number of turns on either side and acts merely to separate the D.C. supplies to either subscriber and also makes possible independent signaling from either subscriber. The circuit shown as "B" is also used for connecting subscribers in the same exchange district and is the type employed frequently with certain machine switching systems. This circuit also supplies current to each loop independently and makes possible independent signaling. Circuit "C" of Figure 5 is a type used in some P.B.X. systems. This circuit, although giving independent signaling, does not give independent current supplies. It is, therefore, not as satisfactory where there are considerable differences in the length of the loops, as will be pointed out shortly.

In addition to these three types of cord circuit used in common battery exchanges, there is of course the circuit required for magneto exchanges where the transmitter battery is furnished from a local source in the subscriber's set and the signaling is by means of a magneto operated by the subscriber. Such circuits are usually of the form shown in "B," Figure 5, except the relays and battery are replaced by two single winding drops which operate on the A.C. furnished from the magneto of the signaling subscriber, and are connected directly across the line on either side of the two condensers.

The two principal functions of the common battery cord circuits are, as mentioned above, to transmit efficiently across the junction of two circuits the voice frequency currents generated at the transmitter of either subscriber and to supply adequate direct current from the common battery to the subscribers' transmitters. The efficiency of the cord circuit can therefore be thought of as consisting of two parts, (1) voice frequency efficiency, and (2) the current supply efficiency.

The voice frequency efficiency is of course dependent upon the actual impedance of the two lines being connected. These line impedances are in turn affected by the length and character of the loop connecting the subscribers' sets, as well as the type and characteristics of the subset. The current supply efficiency is primarily a function of the transmitter characteristics and is dependent on the D.C. resistance of the complete circuit through which the direct current flows. The efficiency of a transmitter varies with the D.C. supplied in the manner shown in Figure 6. It is readily seen that this D.C. passing through the transmitter depends upon the voltage of the central office battery and upon the resistance in the circuit which includes that of the cord circuit, the loop and the subscriber's set as well as of the transmitter itself, which latter is in turn dependent on the D.C. flowing through it. It is therefore seen that the efficiency of a cord circuit cannot well be stated except for a system in which the elements involved are definitely known. In designing cord circuits from the transmission standpoint it is customary to consider their efficiency under one or more typical conditions and it is usual to indicate this efficiency for a given type of subscriber's set and for various lengths of loop.

One of the important factors in the efficiency of the cord circuit is the D.C. resistance of the windings of the coils or relays. Obviously a circuit which may have excellent voice frequency efficiency might have such high resistance that very little direct current would be supplied to the subscriber's transmitter. The talking efficiency of a system using such a cord circuit would be low and could quite properly be charged to the inefficiency of the cord circuit. From this standpoint, then, a cord circuit having no D.C. resistance would be the desirable thing. Such a circuit is, of course, impossible and the actual circuit must be a compromise between low resistance and such matters as size and cost of the apparatus, for it is conceivable that it would be possible to build a repeating coil having a negligible D.C. resistance by using very large gage wire for the winding. Such a procedure although giving low current supply losses would result in a repeating coil of very large size, which would be expensive and would naturally not be practicable.

With a circuit of the type shown as "C," Figure 5, another factor is involved. The current for both subscribers' transmitters is supplied through the same coil. If one subscriber's loop is very much shorter than the other, the short loop will tend to take the major part of the D.C. and the transmitter on the longer loop will re-

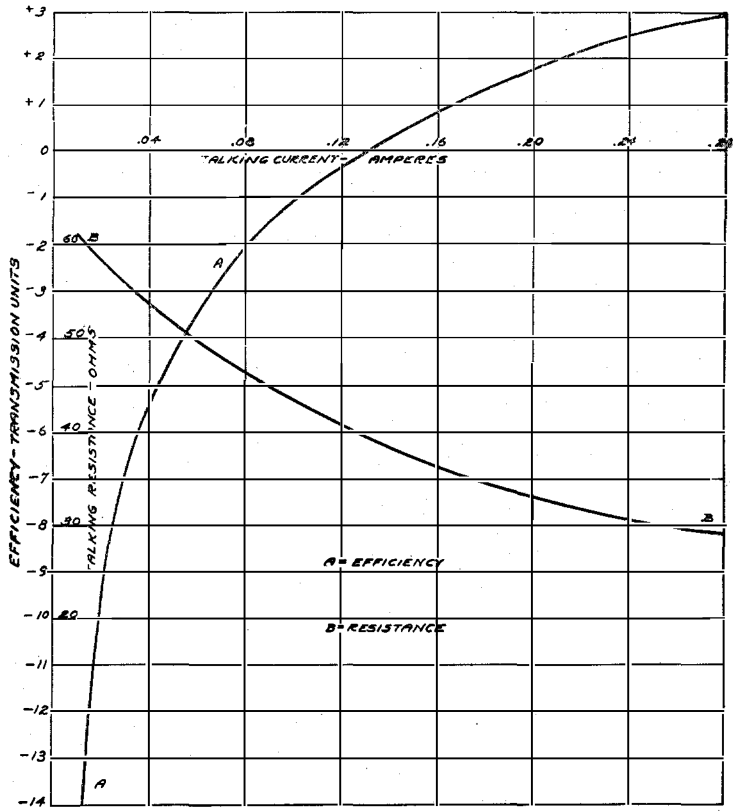


Figure 6—Current Supply Loss and Resistance Characteristic for Shop Product No. 323 Transmitter

ceive less current than would be the case with a cord circuit of the same resistance and operated from the same voltage, but of the types of "A" and "B."

Although the efficiency-frequency characteristics of cord circuits differ somewhat, this has not been, in general, a determining factor in their design since the conditions under which they are used will largely determine this characteristic and favor one type of circuit in one case and the other in a second case.

Transmitters

Reference has already been made to the characteristics of transmitters as regards their change of efficiency with direct current supply. This applies to the commercial types of carbon granule transmitter generally employed. Such transmitters are considerably more efficient at frequencies near the middle of the transmitted voice range, and as previously mentioned are a source of some non-linear distortion.[34] These commercial types of transmitter cannot therefore be used for such purposes as broadcasting where naturalness is more important than efficiency. The lack of efficiency in high quality transmitters can be overcome in broadcasting by the use of suitable amplifiers which could, of course, not be employed economically at a subscriber's set.

Receivers

Although some types (electromagnetic) of receiver obtain the necessary magnetization by means of direct current through the winding, the majority of telephone receivers are of the permanent magnet type. Common types of receiver are also more efficient at the middle frequencies in the voice range than at other frequencies.

Subscribers' Sets

In practical two way telephone systems the transmitter and receiver must be connected to the telephone line in an efficient manner. In certain cases it is permissible to disassociate the transmitter when listening in order to save local batteries as is the case with certain types of sets used on train dispatching circuits,[18] but in general the receiver and transmitter are permanently associated with the line when in use.

The problem of designing a subscriber's set is therefore one of connecting the receiver and transmitter to the line in such a way as to give the maximum transmitting and receiving efficiency when all other factors of importance are taken into account.[16]

In the case where it is permissible to use a variable set; i. e., one in which only the transmitter or the receiver is connected at a time, the maximum efficiencies are obtained when the resistances of the instruments are equal to that of the circuit with which they are associated and when the reactances are annulled. When it is not feasible to annul reactances the maximum efficiencies are obtained if the impedance of each instrument is equal to that of the associated line or circuit.

When the transmitter and receiver are connected to the line in a permanent relation, the series arrangement shown in Figure 7-A is generally the most suitable.

It is obvious that with such an invariable circuit and with finite impedances for both the transmitter and receiver, neither the transmitting nor receiving efficiency will be as high as in the case of the variable set, since part of the total power on transmitting is wasted in the receiver, and on receiving some is lost in the transmitter.

Assuming that such a set is used in conjunction with a similar one at the other end of a long connecting line, the problem becomes one of transmitting the maximum power into the line at one end and absorbing the maximum at the other end, or in other words, of obtaining maximum overall (combined transmitting and receiving) efficiencies. This can be shown to be obtained when, for the same phase angles throughout, the effective impedance of the receiver and transmitter are equal to each other and their sum, which is the impedance of the set, is equal to the impedance of the line as measured from the set terminals.* In general, the impedances of the transmitters and receivers commercially available may not have the necessary values. By inserting a transformer between each and the set as shown in Figure 7-B, the impedances may be stepped up or down to the proper values.

Within limits it is relatively simple to change the impedance of the receivers commonly used

* See Reference 16, page 107.

by merely changing the number of turns and size of wire on the windings, so that the receiver can be made to have the desired impedance, eliminating the necessity of any transformer. This is not the case with the usual carbon granule

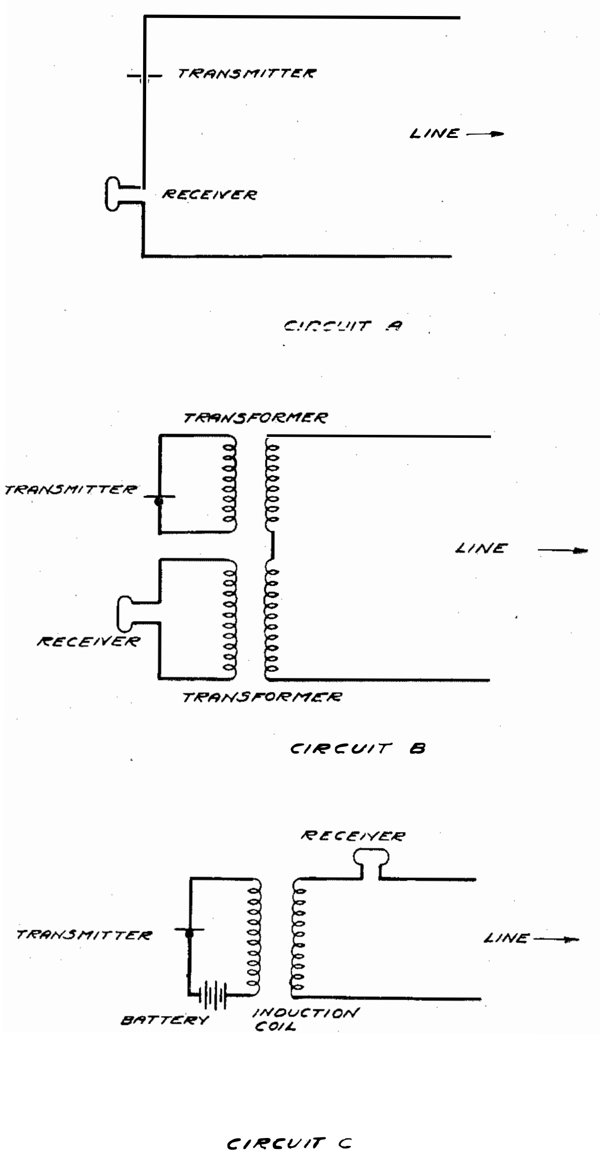


Figure 7—Types of Subscribers' Sets

transmitter and in fact there are objections and difficulties to producing one of the necessary high impedance. The circuit then takes the form shown in Figure 7-C, which is the ordinary local battery type set.

It is interesting to note that the transmission over any system using sets of this invariable type is inherently about 6 *TU* worse than that over a similar system using variable substation circuits.*

In the practical design of substation circuits considerations other than maximum overall efficiency must be taken into account. Due to the line noises which are present to a greater or less extent on all circuits, it has been found that it is advisable to increase the transmitting efficiency even at the sacrifice of some receiving efficiency. That is, by increasing the transmitting efficiency of the set towards that obtainable with a set in which the transmitter is connected most efficiently to the line, more transmitted current is sent into the line. The disturbing noises are therefore less comparatively. By doing this the receiving efficiency is somewhat decreased, but as the noise is decreased as much as the speech the net result of this adjustment is an improvement in the clarity of transmission. The total overall efficiency of such a set is also somewhat less than the maximum possible.

The better grades of common battery telephone sets use an induction coil and a condenser combination which gives a transmitting efficiency about one *TU* less than the absolute maximum which could be obtained with an ideal coil and condenser using, of course, the same transmitter and receiver. The receiving efficiency is about 2 *TU* less than the ideal. In other words, if an infinite amount of money were to be spent on the circuit or upon the induction coil, condenser, etc., it would only be possible to improve the overall efficiency of such a circuit about 3 *TU*. Consequently, to get any very large gain (such as 3 or more *TU*) in the overall efficiency of the present type of standard common battery set, it must be accomplished by the use of instruments that are inherently more efficient, and not by the use of any new or improved type of invariable substation circuit.†

Before leaving consideration of the substation set, there is one more characteristic of the invariable set of the simple type discussed which is important. This is the current in the receiver while transmitting. This current produces a sound of the speaker's own voice and is commonly known as side tone.

Within limits some side tone is, in general,

* See Reference 16, page 108.
† See Reference 16, page 114.

desirable, but with certain types of set it is at times excessive, the energy into the receiver being approximately equal to that going into the line. This, of course, means that the talker's voice sounds very loud in his own receiver, and that while listening, any room noise will appear as a disturbing sound in the local receiver, tending to obscure the received voice sound, thus effectively decreasing the efficiency of reception. Furthermore, with loud side tone the subscriber will feel that he is talking louder than is actually the case and will, therefore, tend to lower his voice, with the result that outgoing transmission is decreased.

There are many possible forms of anti-side tone circuit. All efficient invariable anti-side tone circuits require one more element than the side tone circuit. This additional element is known as the balancing network. The necessity for this may be shown by briefly discussing the action of an anti-side tone set. The operation of the anti-side tone circuit is based on the Wheatstone bridge principle, in which a balance is obtained between the line and a network having the same impedance as that of the line. As an example, a circuit is shown in Figure 8, which is the type used in a recently developed train dispatcher's set.[18]

In this figure, the analogous Wheatstone bridge circuit indicates the relation between the various elements. It is obvious from this that providing B is equal to C and the network N has the same impedance as that of the line L, no current will flow in the receiver from an electromotive force connected across the bridge since a balance exists. On the other hand, any electromotive force in the line L will cause current to flow through the receiver. The first mentioned arrangement corresponds to the transmitting condition of the set, and the second to the receiving condition. In the actual circuit the transmitting voltage is applied to the bridge network through the coil, the two windings C and B of which are balanced; but this does not alter the bridge analogy. This arrangement also makes it possible to include the resistance component of the network as a part of the resistance of the winding C. This may be accomplished by either using a small gage wire for winding C or adding some high resistance wire.

The impedances of telephone lines vary considerably over the range of telephone frequencies. Furthermore, different lines, such as those generally used in dispatching work, may differ appreciably. It is, therefore, not possible nor practicable to design a single balancing network to exactly equal the impedance of different lines at all frequencies of interest. A compromise must be used, but it is possible to obtain sufficient balance by this means to produce a considerable reduction in the current flowing in the receiver circuit while transmitting.

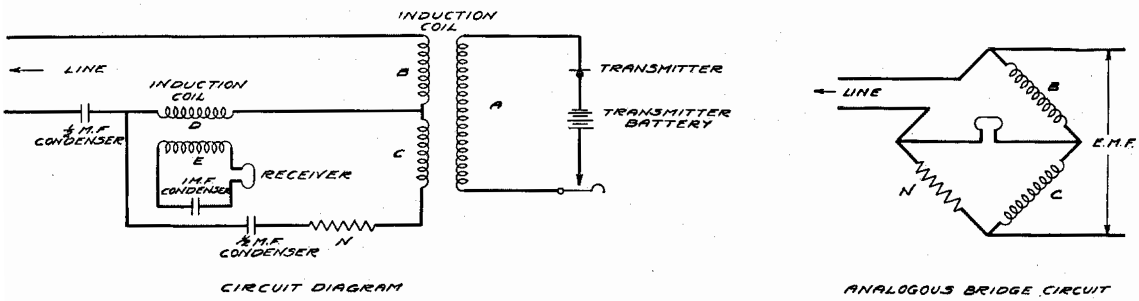


Figure 8—Anti-Sidetone Dispatcher's Set

The ideal anti-side tone circuit is of the same overall efficiency as the ideal sidetone set. In practice, however, the anti-side tone set will be slightly lower (1 $TU \pm$) in efficiency due to the fact that a perfect balance is not obtained and some current flows in the receiver while transmitting and some in the network while receiving.

In the discussions given above on substation sets, the local battery type has been primarily used as an illustration of the points in question. Due to the necessity for supplying the current required for the transmitter from a central source, the circuit arrangements of the common battery sets are somewhat more involved, but the underlying principles are the same as those just considered.

Line Characteristics

In power transmission lines where the frequency of the applied voltage is low, the line losses are small and the effective circuit impedance is largely determined by the impedance characteristics of the connected electrical equipment, such as transformers, motors, etc. The impedance* of the transmission circuit may be raised by raising the impedance of the equipment; by this means the line losses may be decreased since the necessary current for transmitting a given amount of power will be less. with consequent lower resistance losses.

In telephone transmission lines, as already mentioned, the line losses are large and only a small part of the impressed power is utilized in the receiving equipment. In such cases the circuit impedance is practically determined by the constants of the line itself, the terminal equipment having little effect on its value. Any increase in impedance of the line with consequent decreased losses must be accomplished by modifications in these line constants.

The two characteristics of a line which are of most use in telephone engineering are its characteristic or iterative impedance and its propagation constant. The characteristic impedance of a line is the impedance of a line of infinite length as measured at one terminal. With such an infinite line, if it is cut at successive points the impedance at these points towards the distant end will, in each case, be the same; hence the term iterative impedance. In a line of uniformly distributed constants the propagation constant is a factor which gives a measure of the change in magnitude, as well as phase, of the current and voltage for each unit length of line. The propagation constant has two components; the one known as the attenuation constant which is a measure of the logarithmic decrease in current and voltage per unit length; the other is generally called the phase or wavelength constant and is a measure of the phase shift per unit length. The wavelength constant also provides a means of determining the velocity with which an electric wave is propagated over a given line.† The length of line necessary to cause a phase shift of 360 degrees is, of course, equal to one wavelength. The total attenuation of a line is obtained by multiplying the attenuation constant by the length of line, and the total phase shift by multiplying the wavelength constant by the length of line.

The line constants which determine these two line characteristics are the line resistance R, the leakage between conductors G, the inductance L, and the capacitance C. The values of the characteristic impedance and the propagation constant are also functions of the frequency.‡

In non-loaded cable circuits both the impedance and the propagation constant vary greatly with frequency. In particular the attenuation over non-loaded cables increases so rapidly with frequency that good quality of transmission cannot be obtained over any great length even with repeaters to overcome the attenuation, unless compensating means are used to equalize the change in attenuation. Open wire lines, however, due to the effect of the appreciable amount of inductance, have relatively constant impedance and attenuation for voice frequencies. If the conductors of a cable circuit are provided with uniformly distributed inductance by means of iron wire wrapped continuously around the conductors, the attenuation will be decreased and become relatively uniform over a wide frequency range. This is one means of loading cables and is known as continuous loading.

Such a method, although of advantage in certain cases,[10, 11] such as long submarine cables, is not in general as economical or satisfactory as the coil loading which is widely used throughout the world on cables having a considerable number of conductors. As is well known, such loading consists of inserting inductance coils in series with the conductors at uniform intervals through-

* The impedance of a circuit is the vector ratio of impressed voltage to current flowing. By using high voltage transformers the voltage on the line is increased but the current is decreased; therefore the circuit impedance as measured at either end of the transmission line will be increased.

† Since the wavelength constant is the retardation angle (in circular radians), the velocity of propagation of a wave of angular velocity, w, is in general this angular velocity divided by the wavelength constant. See "Transmission Circuits for Telephone Communication," by K. S. Johnson, p. 146.

‡ For a line of uniformly distributed constants R, G, L, C, the characteristic impedance is given by $Z_0=\sqrt{\dfrac{R+jL\omega}{G+jC\omega}}$ and the propagation constant by $P=\sqrt{(R+jL\omega)\,(G+jC\omega)}$. Both Z_0 and P are complex or vector quantities. $\omega=2\pi f$, where f is the frequency.

out the length of cable. The more frequently these coils are placed the more nearly the system approaches the condition of uniformly distributed constants.

The use of inductance decreases the attenuation by raising the impedance of the line so that for a given power input the line current, and consequently the line losses, are lower than in the non-loaded cable circuit. There are numerous factors entering which limit the extent to which these advantages can be practically realized. On such circuits over a considerable range of frequency the attenuation is more uniform, and the speed of propagation of the electrical wave is slower than on non-loaded circuits. This latter is an important factor on very long circuits.[4]

When loading on circuits is accomplished by inductance coils spaced at uniform intervals; i. e., lumped loading, the combination of the coil inductance and the circuit capacity occurring between the loading points, constitute an electrical structure known as a filter. A filter of this type is known as a low pass filter and has the characteristic of transmitting with small attenuation all current of frequencies below a certain critical frequency. Above this value, however, the attenuation increases very rapidly. In designing loading systems, this characteristic must be taken into account since the transmitted frequencies must include a range sufficiently wide to give the desired quality. The frequency band required to give a commercial grade of long distance transmission is considerably less than is required for the transmission of radio broadcast programs.[29]

In this country two weights of loading are usually employed on the long distance cable circuits. These are H-174-S formerly known as "medium heavy" and H-44-S, formerly known as "extra light" loading. The former has an inductance of about 0.174 h. in the side circuit spaced 6000 feet apart; the latter uses 0.044 h. coils on the same spacing.[4]

The H-174-S side circuits have a characteristic impedance of about 1600 ohms and a cut-off frequency of about 2800 cycles. The H-44-S side circuit has an impedance of about 800 ohms, and a cut-off frequency of about 5600 cycles.

To illustrate the effect of weight of loading on the attenuation of circuits, Figure 9 is included. From this it can be seen that the heavier the

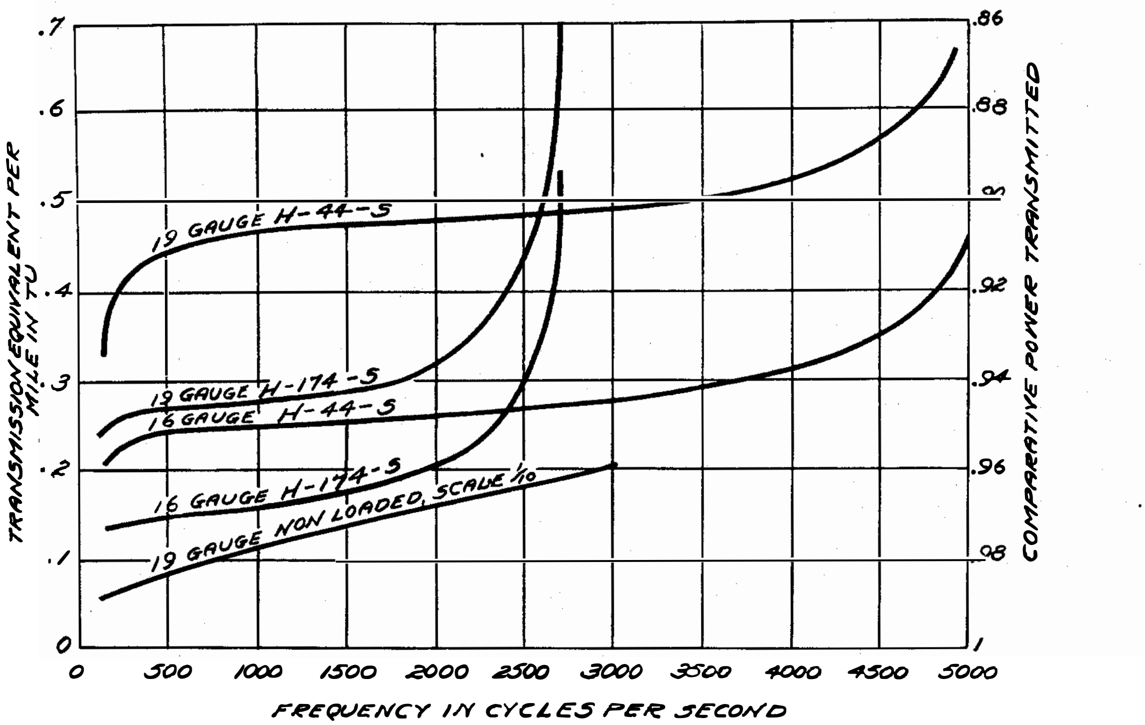


Figure 9—Attenuation-Frequency Characteristics of Loaded Cable Side Circuits

loading the lower the attenuation for the transmitted frequencies and also the lower the cut-off point. Practically the cut-off point is not sharply defined so that as the frequencies approach this value there is a noticeable increase in attenuation.

REPEATERS[3]

Although loading provides a means of considerably increasing the distance over which telephone circuits may be operated, the attenuation of long telephone circuits is still so great that some means of amplification must be employed where the telephone lines are extended to the distances now practicable.[7]

Although telephone repeaters of mechanical construction[3] have been used the vacuum tube repeater is considered superior on account of its relative freedom from distortion, high amplification, and constant operation compared to any mechanical type yet produced.

Two types or classes of repeaters which are in most general use are known as the 21 and 22 types. The 21 type is a two-way repeater using one amplifying element; the 22 type is a two-way repeater using two amplifying elements. Each type has its own useful field.

A two-way repeater has an analogy in the anti-side tone set already discussed. In Figure 10 is shown a simplified anti-side tone set similar to that of the dispatcher's set shown in Figure 8. If a second line is substituted for the balancing network having an impedance characteristic similar to that of the first line, and the receiver is placed immediately adjacent to the transmitter so that any sound produced by the receiver will actuate the transmitter, a 21 type repeater circuit is obtained.

Briefly the repeater action is as follows: Energy coming in from either line divides approximately equally between the receiver and the transmitting or output element. That part which goes directly into the transmitting element is lost, dissipated as heat. The energy going into the receiver, however, actuates the transmitter producing amplified energy from the output which is transmitted into both of the lines.* If the two lines are similar none of the amplified energy returns to the receiver on account of the balanced action previously described. If the similarity of the lines is not exact, and depending on the amount of amplification produced by the receiver-transmitter combination, more or less energy will be returned to the input of the repeater element and local oscillations or singing may result. If a vacuum tube repeater element is substituted for the one shown, the resulting

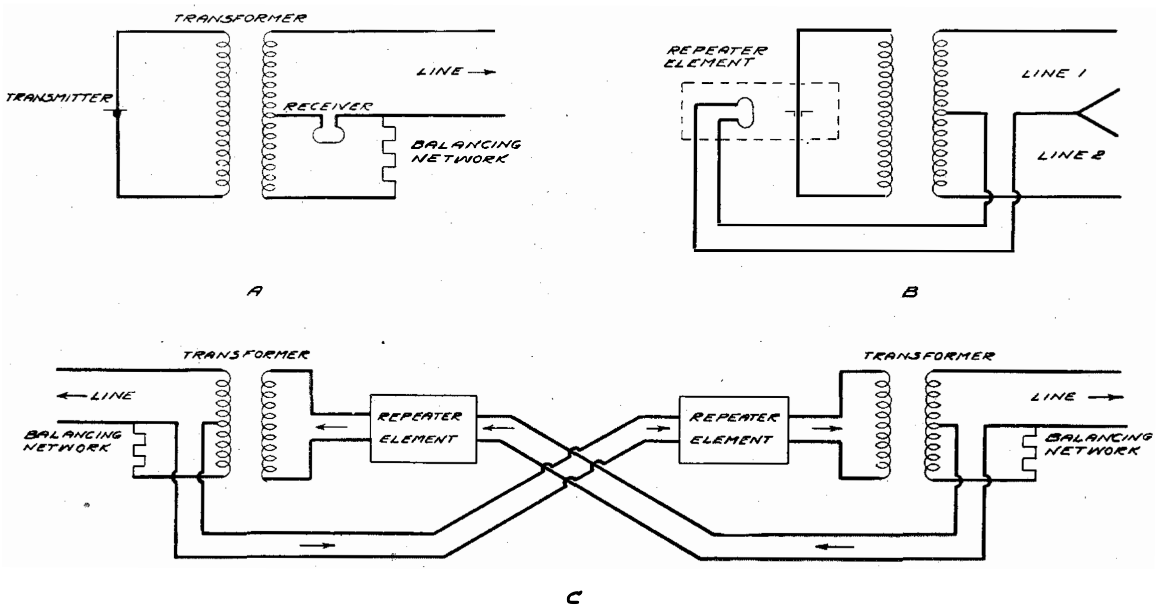


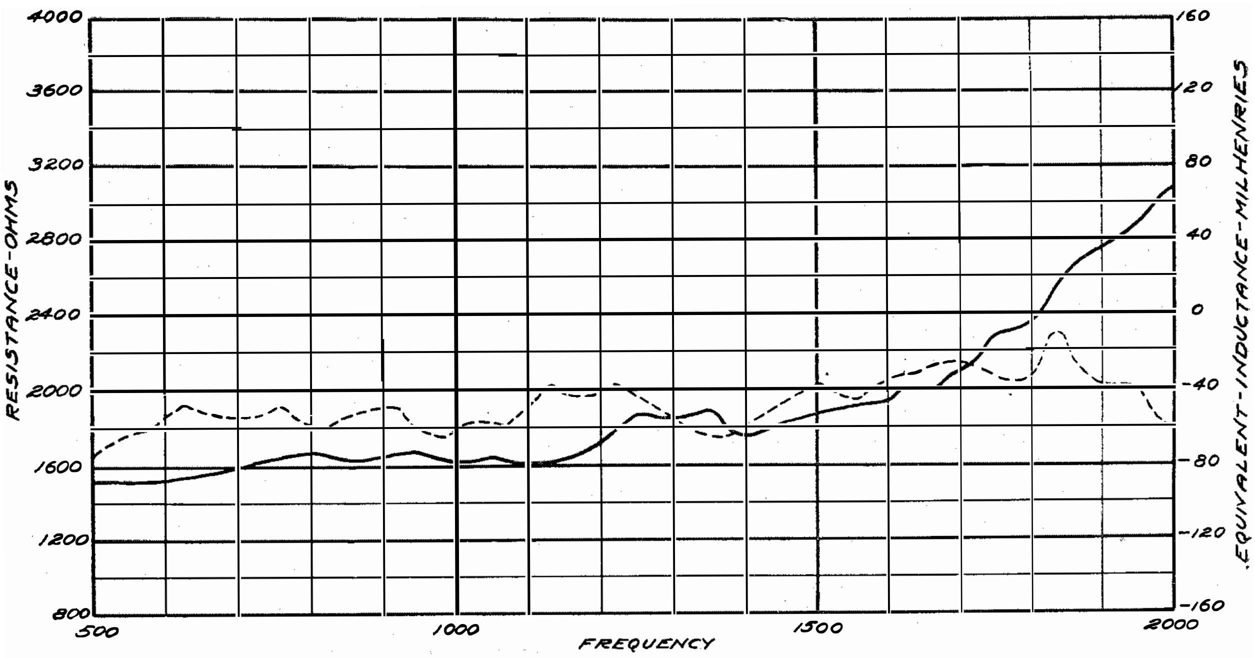
Figure 10—Analogy Between Repeater Circuits and Anti-Sidetone Substation Set

* This characteristic of the 21-type repeater of sending amplified currents in both directions limits its use to lines having only one repeater.

circuit is that of the commercial form of 21 type repeater.

Since the satisfactory operation of this type of repeater is dependent on the similarity of the two lines which it connects, its use is somewhat limited and confined to operation at or near the mid-point of a given section of a uniform circuit. Where more than one repeater is required on a line or two dissimilar lines are to be connected with a repeater, separate balancing equipment is used for each line. In this case approximately half of the amplified energy will be dissipated in the network. As may be seen from the diagram, in order to get two-way amplification two balanced circuits and two repeater elements are required. The circuit is shown schematically in Figure 10-c. This is the form of the commercial 22 type repeater.

In practice many precautions must be observed in order that the impedance of the line may be sufficiently uniform to make possible the necessary degree of balance with a network of reasonable simplicity.[22] Telephone lines to be used with repeaters should be of very uniform construction, and should not have sections of widely different construction mixed between repeater points. In loaded circuits the inductance and spacing of the loading coils must be held within close limits. Even with the most careful construction and installation some irregularities in the impedance of circuits occur. Figure 11 shows the impedance of a typical circuit. Due to these numerous small irregularities and the impracticability of building balancing equipment to simulate the line impedance exactly, the possible amplification practically obtainable is limited by the singing point caused by the lack of balance between a line and its network. It is, of course, not possible to operate a repeater right up to the maximum gain possible without actual singing, since distortion of the amplified currents occurs as the singing point is approached.



Resistance ———— Equivalent Inductance - - - - -

Figure 11—Line Characteristics—A Cable Circuit in Normal Condition

On loaded circuits the impedance of the line changes greatly near and above the cut-off frequency. To design equipment which will give a good balance at frequencies in this region is entirely out of the question commercially. By the insertion in the repeater of low pass electrical filters having a cut-off below that of the line, currents of frequencies near or above the line cut-off are prevented from circulating and it is, therefore, only necessary to design balancing equipment simulating the line impedance up to the cut-off frequency of the filter.

Noise and Crosstalk

The limitation of extraneous currents in telephone circuits, whether arising from inductive interference or crosstalk, is a matter of equal importance with the transmission characteristics of the system. Without proper precautions, extraneous noise may be introduced into a telephone circuit by inductive interference from power lines in the neighborhood of the telephone lines. Such interference is manifest in the production of line noises of various types ranging from clicks to steady noises. By suitable design of the circuits and, particularly, by proper coordination of the telephone and power lines,[9] such troubles may be minimized.

Crosstalk between two circuits, moreover, may be due to improper design, installation, or maintenance of the circuits, and is caused fundamentally by unbalances between the two circuits in question or by some impedance common to both the disturbing and disturbed circuits.

One means of minimizing inductive interference is by transpositions in the telephone and power lines.[5] Transposing consists in interchanging the wires of a circuit at frequent intervals so that the voltages induced in one section will be equal and opposite to those induced in an adjacent section. Transpositions in the disturbing lines tend to cause the induction of neutralizing potentials in adjacent sections of each of the wires of a metallic telephone circuit, while transpositions in the disturbed circuits tend to cause an equalization of the induced voltages on the two wires of the circuit. Transpositions in the disturbing lines do not directly affect induction arising from the residual voltages and currents, and transpositions in the disturbed lines do not affect voltages induced between wires and ground. By residual voltage is meant the vector sum of voltages to ground of the various wires of the circuit and by residual current the vector sum of the various currents in the wires.

Complete neutralization of the inductive effects by means of transpositions is not possible practically, both because of the existence of the residual voltages and currents and also because of numerous irregularities in the exposure conditions, but systems have been developed which greatly minimize crosstalk and inductive interference. Unbalances between the closely associated circuits of paper insulated cables are minimized by the frequent twisting of the wires of a pair and the pairs of a quad and by the opposite stranding lay of the adjacent layers. The capacity unbalances which occur between the wires of one circuit and those of another may be the cause of serious crosstalk if means for reducing them are not used both in the manufacture of the cable and in their installation.[33]

In the multiple twin or quadded type of construction generally used in this country, two pairs of wires, each of which has a different twist, are laid together with a third length of twist to form a quad. Quads so formed are stranded together to form a cable.[8]

By means of careful manufacture of individual cable lengths [33] and the use of proper twists, the capacity unbalances between circuits in different quads can be kept down to reasonably low values. Also in sections of installed cable these unbalances can be kept to suitable values by mixing the quads at each joint so that any two quads are adjacent for as short a distance as possible. Unless special corrective measures are taken, however, the unbalances between the three circuits of a quad (two sides and a phantom) will be high enough to cause excessive crosstalk. Unbalances between circuits within a quad are more serious from a crosstalk standpoint than the unbalances between circuits in adjacent quads, because the former type of unbalance is inherently larger and because they occur between circuits which are always adjacent throughout the whole length of cable, while the latter type of unbalance is between circuits which can easily be separated for the greater part of the distance.

The means generally used in this country for reducing these unbalances between the circuits of a quad, consist in a method of transposing or crossing conductors at certain splicing points during installation of the cable. The particular crossing scheme to be used for each quad test splice is determined from the results of unbalance tests made with a capacitance unbalance bridge. These measurements will determine which quads to connect and which of the several methods of crossing the four wires of the two quads will give the minimum net unbalance throughout the length of the quad in a given section of cable.

The tests are usually applied to each loading section so that the unbalance will be as nearly neutralized as possible between loading points. Other tests are also applied to minimize the unbalances throughout a repeater section consisting of forty or fifty loading sections. These latter tests include the unbalance due to the loading coils.

Before leaving the subject of capacitance unbalance, it may be well to show briefly what is meant by this. In Figure 12 are shown schematically the four wires of a quad, conductors 1 and 2 forming one pair and 3 and 4 the other. The eight capacitances between the wires of different pairs and between these and ground are also indicated. The resemblance to a bridge circuit is at once apparent. If an alternating current voltage is applied between the conductors 1 and 2, no tone will be heard in the receiver connected across conductors 3 and 4 if the capacitances are balanced; or, in other words, if the conditions for an equal arm bridge balance exist, *i. e.*, a equals b, and d equals c, since the capacitances to ground, e, f, g, and h can practically be neglected.

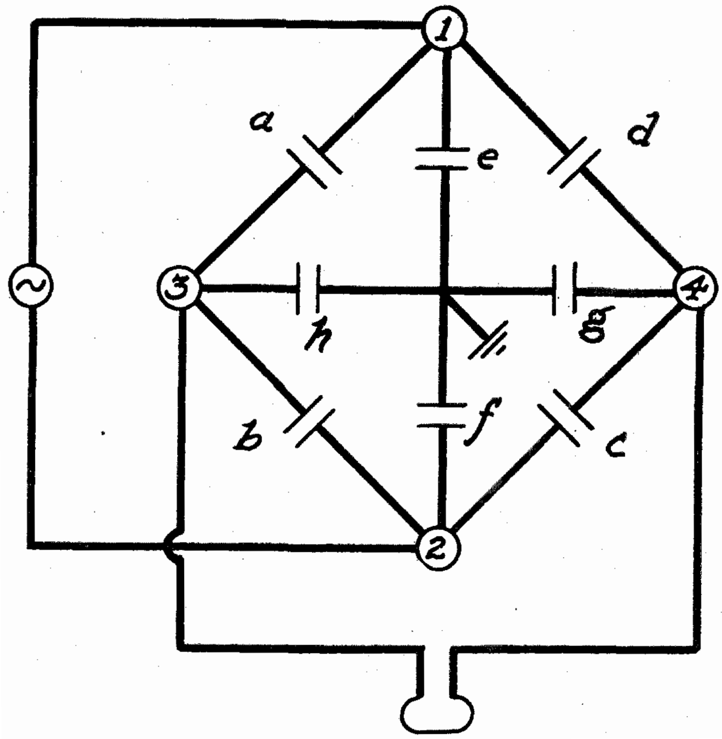


Figure 12—Schematic Illustration of Capacities Between the Four Wires of a Quad

This condition assures side to side balance. A similar analogy can be drawn for phantom to side balance.

In using phantom circuits it is necessary that the impedances of the two conductors of each pair or side circuit of the phantom be closely equal.[31] Unless this is so, the phantom circuit current will be different in the two conductors of the side circuit, a potential difference will be produced and phantom to side crosstalk will result. This is illustrated in Figure 13 where R and R′ represent series and shunt unbalances. It may readily be seen that either one or both of such balances will cause a difference between the phantom currents in the two side circuit conductors of side circuit No. 1 with resultant phantom to side crosstalk. It is also evident that the phantom repeating coil must be carefully balanced as regards impedance of the two parts of the phantom winding.

Other types of interference which may cause difficulties on circuits using superposed telegraph are known as "Morse thump" and "Morse flutter." "Morse thump" is due to inadequate compositing equipment or excessive telegraph currents, and is evidenced in the telephone circuit by the typical low frequency thump of the telegraph signals. "Morse flutter" occurs only on loaded circuits and is due chiefly to an increase in the effective resistance of the loading coil while a telegraph current is superposed on the circuit.[38] This causes an increase in the attenuation of the circuit to telephone currents and is noticed by a fluttering in the loudness of the received speech in accordance with the telegraph signals. A special low current metallic polar duplex telegraph system [37] has been developed for use with loaded repeatered circuits which overcomes this flutter trouble. The current required by the ordinary ground return telegraph circuits is too great to give satisfactory service on such circuits.

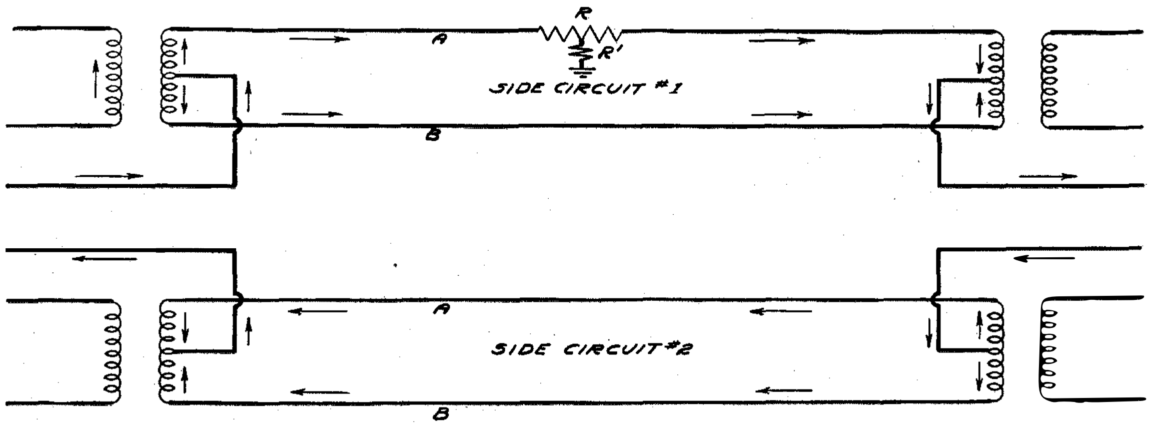


Figure 13—Schematic Illustration of Impedance Unbalances in a Phantom Circuit

Layout of Local and Long Distance Circuits

In commercial telephone practice the question is, of course, how to obtain a given grade of service for the least annual cost.[23] That is, two systems may give equally good results, but one may be considerably lower in annual cost than the other. Other things being equal, the system having the lower annual cost would be adopted.

In order to obtain the most economical plant,[36] it is necessary to look forward a number of years, estimate the probable growth of service and initially provide certain facilities in excess of immediate needs. The amount of excess plant which should be provided depends, among other things, upon the type of equipment, the annual charges on this equipment, and the cost of adding further equipment of the same type when the original facilities become inadequate.

As an illustration, take the matter of underground cable ducts. It is obviously an expensive matter to dig up a street and place a single additional duct in place each time a new cable is required. It may be cheaper to install several ducts initially. Using present worths* as a fair basis of comparison, the present worth of all the annual costs over a number of years by this method would probably be less than that for frequently digging up the street and installing another duct. Of course, the exact number of ducts which will be economical to provide initially will depend on numerous factors which should be given careful detailed consideration when making fundamental plans since inadequate investigation of this phase of the subject may lead to serious errors and a very uneconomical procedure.[23]

Another very important point to consider in a study of fundamental plans is the location of the central offices. These should be so placed, if possible, that they will serve the necessary number of subscribers with the minimum effective annual cost of loop and trunks over a long period of time. This necessitates a careful consideration of the probable geographical location of prospective subscribers, and should

* By "present worth" is meant the sum of money required in hand at the present time to meet an obligation falling due at some future date.

include due attention to the probable direction of future expansion, in order that the central offices may be placed as near the center of service as possible, giving a considerable saving in the cost of loop cable and ducts. The theoretically desirable location may not be available and the choice may, therefore, be between two locations somewhat distant from the ideal. A study should be made of both of these locations and the more economical one chosen.

In planning long distance circuits, not only should the type of circuit be given economic consideration, but the choice of route. This should include a study of inductive coordination with power lines, proximity to which cannot be entirely avoided, as well as of the difficulties of construction over any proposed route. Such a study may indicate that to avoid inductive interference, or to materially reduce the length of a route more installation expense per unit length over a certain section will be economical.

In determining the annual costs for any part of the telephone plant, the principal factors involved are the initial cost of the equipment, including right of way and real estate, the service life, junk or salvage value, interest charges on the invested capital, taxes, insurance, administration charge, operation and maintenance. Each of these is determined by other factors, depending upon the type of equipment and the operating conditions of the individual owner of the plant.

In addition to the points just considered, it is necessary to plan the whole system so that adequate grades of transmission will in all cases be given between one subscriber and another. In order to establish universal service there must be some maximum allowable loss for each part of a system in order that in combination with the other parts the overall equivalent shall be within tolerable limits. Thus a maximum allowable loss should be allotted to the substation equipment and loops, to the interoffice trunks, to the tandem trunks, to the switching trunks, and to the long distance circuits. Such a goal has been established in the Bell System.

The above is a very brief consideration of one of the most important phases of telephone engineering, but space prohibits further details.

Maintenance Practices*

The scope of this paper also does not permit of any considerable space being given to the subject of maintaining telephone systems. This subject has been covered quite thoroughly in other available papers. It seems desirable, however, to mention some of the reasons necessitating adequate transmission maintenance,[15] as well as some of the special tests devised for locating troubles detrimental to good transmission.

In order to suitably maintain the telephone system, it is not sufficient to have available suitable testing equipment by means of which defects may be located, but it is also necessary that some routine of tests be adopted. This is advisable in order that such tests be made at reasonably frequent and regular intervals, thereby eliminating the possibility of defects continuing for considerable periods as might be the case if testing work were carried on spasmodically. Certain types of defects are of more frequent occurrence than others and, therefore, tests for their discovery should be made more frequently than others.[19] The carrying out of any of these tests, of course, requires the expenditure of money by the telephone companies for testing gear and labor. The testing program, therefore, should be based on an economic study in which the cost of tests must be balanced against the decreased quality of service, if no tests are made. This is a rather difficult problem for exact solution, so that the maintenance program must be based largely upon experience and must include not only a determination of what tests should be made and how frequently but within what limits the equipment should be held. These considerations all depend upon the types of circuit involved and their relative importance in the system as a whole. In the Bell System, routine instructions are issued to the operating companies covering these matters, and taking into account local conditions and service requirements.

The complete maintenance work includes D.C. measurement as well as A.C. The former type, which include measurements for D.C. resistance and insulation, are relatively well-known and will be omitted from consideration

* See particular References 15, 19, 20, 21, 24 and 34.

here. Attention will be confined to a few of the A.C. tests which are in use in the Bell System.

As previously mentioned, it is important that foreign currents in a telephone circuit be limited to low magnitudes. The presence of such extraneous currents is evidenced by noise in any receiver associated with such a circuit. It becomes necessary, therefore, to determine quantitatively the amount of such noise.[34]

In order to accomplish this, a testing set known as a noise measuring set has been developed. The amount of noise in a circuit is found by listening in a receiver which is alternately associated with the line under test and a calibrated adjustable tone. The test circuit is adjusted until it is judged that the noise from the standard would cause the same interference with conversation as the line noise, although there is, of course, no conversation during the test.

In addition to determining the quantity of line noise, it is often advantageous in locating the probable source of such disturbance, to analyze the noise for its frequency content. A noise analyzer has been developed which provides means for determining not only the frequencies present but roughly the magnitude of the components by comparison with the noise standard of the noise measuring set.

One of the greatest sources of line noise is inductive interference from neighboring power lines. A telephone system is more affected by induced currents of some frequencies than of others. This is due not only to the transmission characteristics of the line and associated equipment, but also to the response characteristics of the receivers and the sensitiveness of the human ear. In other words, induced currents of certain frequencies say sixty cycles, cause relatively little noise, while the higher harmonics of this frequency will produce more noise. The amount of noise which will be set up by a given exposure to a power circuit will therefore depend upon the harmonics of the voltage and current waves. A rating of such waves in terms of their relative interfering effects, when acting under the same conditions, is given by measurements of their telephone interference wave factors with instruments developed for this purpose. These instruments (one for voltage waves and another for current waves) have a frequency response characteristic which approximates those of an inductive exposure, telephone receiver and human ear combined. The actual interference in any given case will, of course, depend further upon many of the factors involved in the relationship of the power and telephone lines.[39]

Another type of disturbance present in the telephone system is cross-talk, as already discussed. Besides the tests for minimizing it as previously mentioned, a direct measurement of its magnitude is desirable. Measurements of this may be made by voice tests, complex tones, or single frequency measurements. The amount of crosstalk between two circuits will vary greatly with frequency. Measurements at a single frequency may, therefore, give very misleading results, and unless a complete frequency run is made, field measurements are ordinarily done with a complex tone, which has been found to give results comparable with voice tests. The crosstalk sets generally in use are arranged so that by making certain adjustments definite fractions of the power sent into the disturbing circuit are delivered to the receiver associated with the crosstalk set. The crosstalk on the disturbed circuit is measured by making an aural comparison between the power from the disturbed circuit and that from the crosstalk set, the latter being adjusted until equal interfering effects are obtained. The crosstalk set is calibrated in units which indicate one million times the square root of the ratio of the received power to the input power.

Crosstalk measurements must be made with great care and it is, of course, important that the measuring apparatus itself be free from sources of crosstalk. Crosstalk sets which are satisfactory for line measurements such as are ordinarily required in maintenance work, are not suitable for crosstalk measurements on certain types of apparatus in which extreme precautions must be taken to insure results of any significance, the measurements of crosstalk in loading coil phantom groups, for example.

In the important case of phantom to side crosstalk when measurements indicate that the unbalances of a circuit are greater than the allowable limit, measurements may be made with an impedance unbalance bridge [31] to obtain an approximate location of the unbalance. It may be usefully applied, however, only to circuits of considerable length and when there are only a few localized unbalances.

Another type of test of great importance in maintenance work is that for determining the transmission efficiency of a circuit. Some consideration has already been given to the question of the measurement of overall efficiencies of systems. Voice tests are at best laborious; a reasonable precision can only be obtained by making a large number of tests. Such a method is obviously unsatisfactory for maintenance work.

Transmission efficiency tests in maintenance work are generally made with single frequencies or standardized complex tones. Considerable study has been required to correlate these tests with direct voice tests, but the advantages have justified the research. In certain cases, efficiency measurements covering a wide range of single frequencies are made. Numerous testing sets have been developed to meet the various types of maintenance work. In general they may be divided into sets for measuring loss and sets for measuring gains. In some sets these functions are combined. The most convenient sets are visual reading sets, calibrated in *TU*, and permit rapid measurements to be made to within .1 or .2 *TU*.

Mention has been made in another part of this paper of the necessity of having lines of uniform impedance, free from irregularities, if satisfactory operation with 2-wire repeaters is to be obtained. Irregularities occur at times and their effect upon the repeater operation may be found by determining the singing point by a test with a 22-type repeater by finding the maximum gain at which the repeater can be operated without singing when it is connected between a line and a network, and the other line is disconnected or shorted.

It is often desirable to obtain further data on the line singing point which is independent of the repeater characteristics and which gives information as to the frequencies causing the lowest singing points. One type of testing equipment for this purpose is designed to measure directly singing points between the line and the network for the frequency range of interest. This set may also be used for measuring repeater gains and for determining the location of an irregularity.

It has, of course, been impossible to mention briefly more than a few of the testing equipments which have been developed for use in telephone transmission maintenance work.

With nearly all these testing sets sources of alternating current are required. These range from single frequency sources up to adjustable sources producing frequencies in small steps from 100 to 50,000 cycles for testing work on carrier current circuits.

Conclusion

Within the limits of a paper of this size it is obviously impossible to treat adequately any one of the several subjects discussed. It is hoped, however, that sufficient has been said on each to indicate the many important factors involved and to tie together the several subjects more fully treated in other papers into a logical whole, which will give a clearer idea of the general subject of telephone transmission than is possible in papers intentionally confined to one phase of this extremely complex engineering problem.

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Testing High-Voltage Cables with D. C. After Installation

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THE development of electrical engineering during the last ten years has been marked by an unprecedented demand for very high pressures in order to cover the long distances over which large amounts of energy must be transmitted. This demand has been met by the introduction of transmission by means of overhead-lines at pressures up to 220,000 volts. Where these lines must pass through or near cities it has become necessary, however, to adopt underground cables as the medium of transmission. The problem undertaken by cable makers has been so to improve and perfect methods of manufacture as to produce cables capable of working satisfactorily at voltages similar to those in use on open-wire lines; and the result of research in this direction has been to develop paper-insulated cables which will operate at 66,000 volts three-phase when the three cores are contained in one cable, and at 132,000 volts three-phase when three single core cables are used. It is not within the scope of this article to discuss the manufacture or operation of the cables themselves, but rather to describe the tests which are applied to ensure the soundness of the dielectric after installation of the cable.

In the days when 10,000 volts was regarded as an optimum value of the working pressure, the most simple and satisfactory method was to apply a high-potential test with alternating current, approximately at double the working voltage. At the present time, however, bearing in mind the lengths of cable under test, this is impracticable owing to the heavy charging current taken by the cable. As an example, consider the size of the transformer which would be required to test a three-phase 33,000 volt cable twenty miles (32 km.) in length, having a conductor cross-section of 0.25 square inch (161 sq. mm.). The electrostatic capacity to neutral would be 0.36 microfarads per mile (0.224 mfd. per km.), and the A.C. testing-voltage would be 66,000 volts (test frequency, 50 cycles).

$$\text{Charging K.V.A.} = 2\pi f\sqrt{3}\, CE^2 \times 10^{-3} = 17{,}000$$

It is manifestly impossible to construct a transformer of this kind in such a portable form that it could be used for the specified purpose.

On the other hand, consider the rating of the corresponding direct-current set, assuming the insulation resistance to be 100 megohm miles and the D.C. testing-voltage to be 100,000 volts.

$$\text{Charging K.W.} = \frac{E^2}{R} \times 10^{-3} = 2$$

In other words a 5-K.W. set is adequate to apply the requisite direct-current voltage for testing long lengths of high-voltage cable; furthermore, the plant may readily be made portable.

THE RATIO OF D.C. TO A.C. TEST-VOLTAGE

There have been numerous attempts to arrive at a satisfactory ratio between the direct-current and alternating-current voltages which will give an equivalent breakdown-test of a dielectric. At the end of this paper, a bibliography of literature relating to this problem is given.

Table I gives in a convenient form the conclusions arrived at by various authorities, and illustrates the diversity of opinion which at present exists upon this matter.

Although the consensus of opinion in published reports favors a ratio of 2.5 for paper insulated cables, the following reasons are likely to result in the adoption of a lower ratio:

(1) While the refinements of modern cable manufacture ensure a very small moisture content, it is impossible to remove the last traces. With an A.C. test under working conditions this moisture remains evenly distributed through the insulation. With a D.C. test, however, the moisture tends to migrate to the negative pole (electric osmosis) and the proportionate percentage of moisture increases at this electrode. Electrolysis causes the generation of gases, and local heating reacts unfavorably on the D.C. test, making it in practice more severe than might be supposed.

TABLE I

Dielectric	Condition	Ratios Quoted by Various Authorities									
		La Porte	Litchen-stein	Peek	Weiset	Intern'l Conf. 1921	A.C.E.C.	Hayden & Eddy	Dutch 1924	N.E.L.A. 1924	Rochow
Air	Dry	...	...	1.41	...	...	1.27	1.41	...	...	...
Oil	Dry	...	...	1.41	...	...	1.33	1.30	...	...	...
Oil	Wet	...	...	<1.41	...	...	...	...	...	...	...
Petrolatum		...	...	...	...	...	...	1.35	...	...	...
Paper	Dry	...	...	...	2.64	...	1.78	1.55	...	...	...
Paper	Wet	...	...	...	...	...	<1.5	...	...	...	...
Paper	Impregnated	...	...	...	...	...	2.83	2.50	...	...	...
Solids	Dry	...	...	Variable e.g. 3.5	...	...	...	1.45 up to 3.45	...	...	1.7
Solids	Wet	...	...	1.41	...	...	<1.5	...	...	...	...
Complete Cables		3 or 4	2.6	...	2.46	2.5	2.37 up to 2.63	...	2.0	2.0 up to 2.4	...
Rubber insulated wires		...	...	...	2.44 up to 2.51	...	...	...	...	...	...

(2) The failure of cable-samples subjected to breakdown-test is due frequently to surges set up by spark-discharges and coronae at the exposed ends of the specimen under test. Since this phenomenon is invariably more severe with alternating-current, breakdowns may occur at lower A.C. voltages than the cable would stand if the ends were properly sealed. The ratio of D.C. to A.C. may be higher when observed in this way than it would be under correct test conditions.

It is suggested, therefore, that a ratio between 1.5 and 2.0 be adopted. Since experiments indicate that the ratio increases as the insulation thickness increases, the 1.5 figure might be adopted up to say 33,000 volts, while above this figure the ratio might approach the limiting value of 2.0.

Table II shows the relative D.C. and A.C. test-voltages usually adopted among English cable makers at the present time.

TABLE II

Working Voltage	Standard Test-Voltage		Ratio DC/AC	Average Thickness of Dielectric
	A.C.	D.C.		
11,000	20,000	30,000	1.50	0.30″(7.62 mm.)
22,000	44,000	75,000	1.71	0.40″(10.2 mm.)
33,000	66,000	100,000	1.52	0.50″(12.7 mm.)

Methods of Producing High Tension Direct Current

Low-Voltage Machines in Series

The method adopted for obtaining high-voltage direct-current with a large power output, as used in such schemes as the Thury-Constant Current Series system, is to couple up a number of low-voltage generators in series to give the required potential, the whole plant being insulated for the full working pressure. Owing to the form of the layout, and the prohibitive cost of the apparatus for small power outputs, this method cannot be followed for cable-testing in the field.

Transverter

A conventional diagram of connections of the transverter developed by Mr. Calverley, of Dick Kerr & Co., England, is given in Figure 1. One can imagine an inverted generator where the armature and commutator are stationary while the magnetic field and brushes rotate, the field inducing an alternating e.m.f. in the stationary armature. Thus in the transverter a three-phase supply induces a rotating field, as in the stator of an induction motor. By abolishing the air-gap between the armature and the field system, thereby increasing the efficiency, a transformer having the usual primary and secondary windings is obtained. By suitably interconnecting the windings, the e.m.f.'s induced in the secondary between pairs of commutator segments can be made to assume their correct phase, and thus a 36-phase secondary voltage is impressed on the commutator. By driving the brushes in synchronism with the A.C. supply, a D.C. voltage can be collected from the commutator, and since the problem of insulation is much simpler with stationary windings, each commutator can be arranged to give 10,000 volts without exceeding the voltage per commutator segment which is usual for D.C. machines. By connecting commutators in series, very high direct-current voltages are available. The transverter is at present commercially

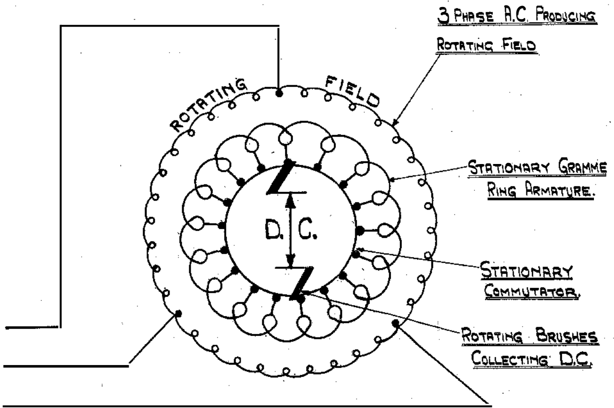

Figure 1—Diagram of Transverter

possible only for large amounts of power, and owing to its large bulk would probably be impracticable as a portable cable-testing set.

Delon Mechanical Rectifier

The principle of the Delon mechanical rectifier is to connect an alternating-current supply in turn to the terminals of two condensers at intervals of 180°, viz., every half cycle the connections are made by means of a rotating brush synchronized with the supply so as to tap off only at the moments of the positive and negative maxima of the wave-form.

In Figure 2, D is an insulated disc carrying a connecting bar C. Assume in position AA the transformer (voltage E, r.m.s.) is at its maximum voltage $(+E\sqrt{2})$. A spark passes across the gap and charges the condenser ac to a potential of $(+E\sqrt{2})$ volts to earth. By the time the brushes C have reached position BB the voltage has reached a negative maximum $(-E\sqrt{2})$ and condenser bc is thus charged to a potential $(-E\sqrt{2})$ volts to earth. The potential difference across condenser ab therefore becomes $2E\sqrt{2}$ volts direct-current, and since the charg-

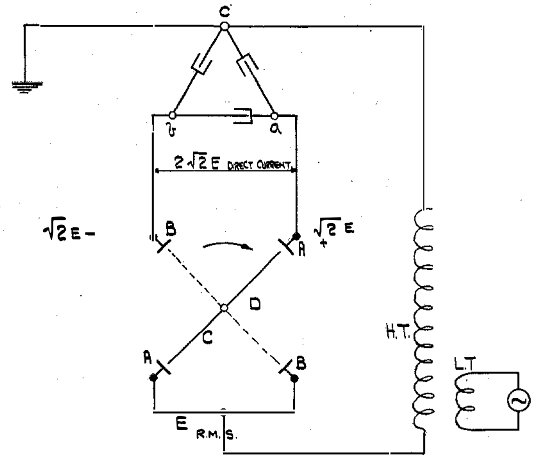

Figure 2—Principle of the Delon Mechanical Rectifier

ing process is continuous the voltage ab is steady and can supply a continuous current for testing purposes. Condensers ac and bc are required to build up the voltages to ground $(+E\sqrt{2})$ and $(-E\sqrt{2})$ respectively.

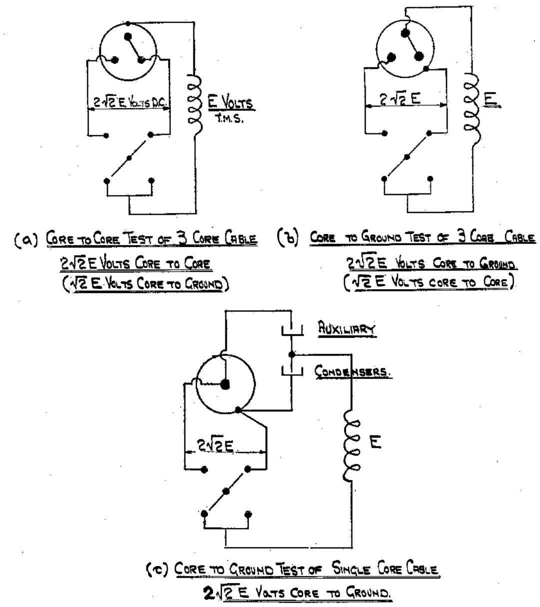

Figure 3—Testing Cables with Delon Rectifier

In the case of a cable-test, the internal capacities of the cable form the required condensers. Figure 3 shows the connections for the three cases of core to core test, core to sheath test, and single core cable-test. It will be observed that in the latter case external condensers are necessary.

Although the Delon rectifier has been used widely for testing high-voltage cables in Great Britain and Europe, experience has shown that much trouble is encountered owing to the fact that the operation of the apparatus depends upon a spark-discharge from the rotating contacts to the stationary collecting brushes, whereby in a greater or lesser degree depending on local conditions, surges and oscillatory discharges

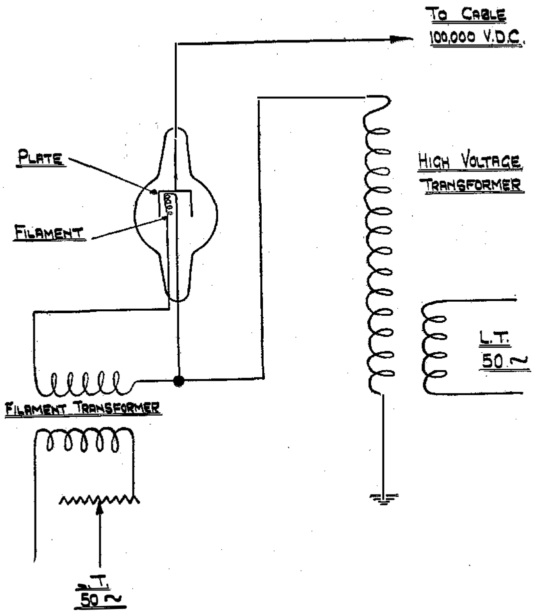

Figure 4—Elementary Circuit for Single Valve Rectifier

may be set up. Such oscillations may permanently weaken the dielectric and possibly cause a failure in the cable. This undesirable feature led to the development of the set adopted by the Construction Department of Standard Telephones and Cables, Ltd., London, for testing all high-voltage underground cables after installation.

Kenotron Rectifier

A natural outcome of the development and extensive use of high-power X-ray tubes with continuous current of the order of 10,000 volts and upwards has been the application of the sources of power so obtained to the testing of cables.

The Kenotron tube depends for its operation on its unilateral conductivity, whereby current can pass through the tube only from the cold electrode (plate) to the hot electrode (filament), the current being due to the emission of electrons by the heated filament and their attraction to the positively charged plate. The elementary circuit shown in Figure 4 indicates how half-wave rectification can be obtained. Such an arrangement is largely used in Europe for making periodic tests, up to 100,000 volts D.C., of underground cable systems, but it has the definite disadvantage that the resultant voltage and output current-waves, since they depend on one-half of the alternating current-wave being entirely suppressed, may show very pronounced ripples.

The introduction of a second Kenotron valve into the circuit eliminates the trouble due to ripples, and theoretical considerations confirmed by oscillograph test-records show that the percentage variation in the high-voltage D.C. may be reduced to 0.5% approximately, provided that the capacities and inductances in the circuit are suitably proportioned. In ordinary commercial cases using 50 cycles A.C. the percentage variation in the D.C. voltage will not exceed 5%.

The arrangement of the circuit is indicated in Figure 5. Step-down transformers T_1 and T_2 supply current for heating the Kenotron filaments, while a step-up transformer T provides high-voltage alternating-current to the rectifier. The arrangement is unidirectional in the sense that it permits only the positive half-waves to pass through Kenotron K_1, thereby charging condenser C_1 to $(+E\sqrt{2})$ volts D.C., and only the negative half-waves to pass through Kenotron K_2, thereby charging condenser C_2 to $(-E\sqrt{2})$ volts D.C. Thus a direct-current voltage $2\sqrt{2}=2.8$ times that of the transformer is set up across the outer terminals of C_1 C_2. In practice, however, a rectification efficiency of 85% is obtained, thus reducing the D.C. to A.C. transformation ratio approximately to 2.4.

Connections of Kenotron Rectifier for Cable-Testing

The two important tests after installation which are specified on high-voltage cables are, first, core to core tests on three-phase cables and, second, core to ground tests on three-core cables or single core cables. Figure 6a shows the connections for the former test, in which the condensers C_1 C_2 in Figure 5 are replaced by the internal capacities of the cable. It is inherent in the apparatus that, for a given test-voltage between cores, a half voltage is built up between cores and ground. Consequently, if E is the specified test-voltage between cores as in Figure 6a, the core to earth voltage is $E/2$.

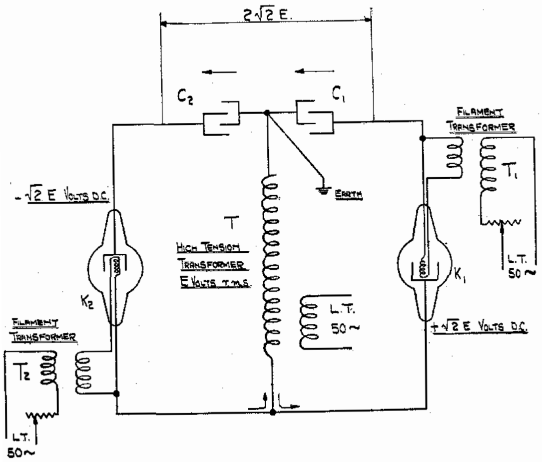

Figure 5—Two-valve Rectifier

Figure 6b illustrates a core to ground test at the full voltage (half voltage between auxiliary core, not under test, and ground).

Operation of Kenotron Rectifier Testing Set

A description will now be given of the portable testing set constructed for Standard Telephones and Cables, Ltd., London, in order to carry out tests on high-voltage cables after installation. Low-voltage A.C. at 220 volts 50 cycles is produced by a single phase alternator coupled to a 10 B.H.P. 4-cylinder petrol motor. This alternator is provided also with a commutator to give 310 volts D.C. for fault localizing purposes. The connections of the rectifier set are illustrated in Figure 7. The low tension A.C. is passed through an auto-transformer to regulate the maximum voltage which can be applied to the transformer terminals, while fine adjustments are made with a movable-iron choke coil which also limits the short-circuit current to a safe value. The transformer is designed for 5 K.V.A. continuous output 220/75,000 volts and has an overload current of 150 milliamperes for thirty minutes (125% overload). Both terminals are insulated for the full voltage to earth.

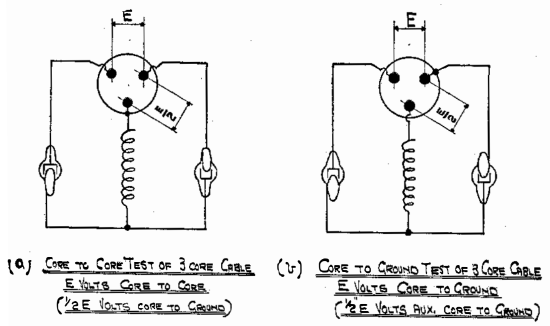

Figure 6

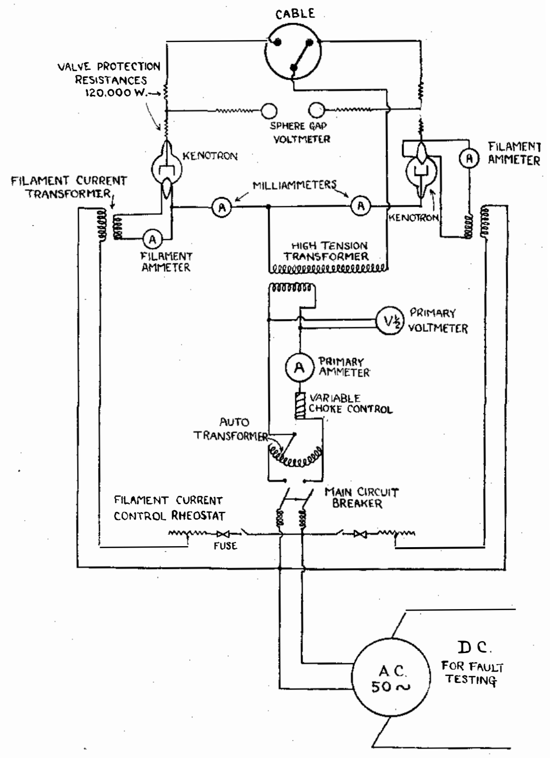

Figure 7—Portable Kenotron Set Connections

Current is supplied to the filaments through step-down transformers 220/8 volts, regulated by resistances in the primary side. It is essential to work the filaments up to, but not in excess of, their rated current, since it is found in practice that the valves will supply only about a quarter of their rated output current of 75 milliamperes when the filament is heated with 6 amperes instead of with the specified 7 amperes. This is due to the decreased electronic emission from the filament and the increased internal impedance of the valve.

On the direct-current side of the set, a milliammeter indicates the charging and leakage current to each tube and thus enables continuous observation of the insulation resistance to be made. A quarter of a megohm wire resistance placed in series with each tube prevents any damage due to sudden overloads or breakdowns, and a sphere-gap voltmeter is connected between the mid-points of these two resistances.

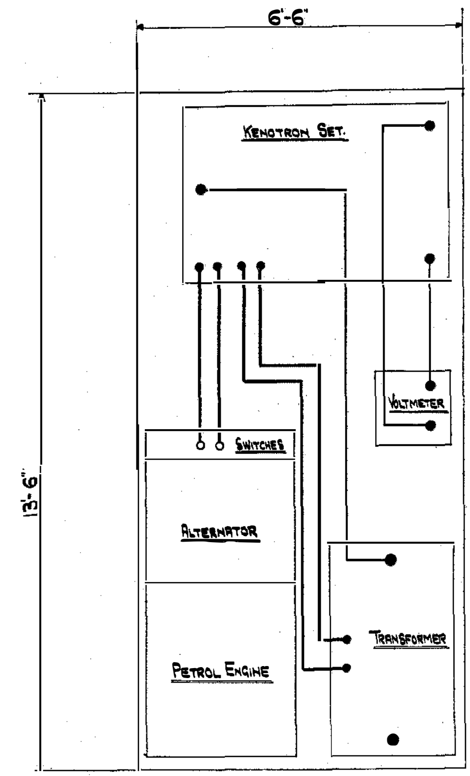

Figure 8—Arrangement of Units—Portable D.C. Test Set

This sphere-gap was originally intended to be used as a cable-discharging device but, as will be explained, it proved to be a source of danger. Voltage measurements are made by means of an Abraham Villard reading directly up to 120,000 volts.

Figure 8 indicates the way in which the various units are conveniently mounted in a trailer which is pulled either by a lorry or by horse power, while Figure 9 shows how one side and end of the van can be dropped down to act as platforms for the operator. The high tension leads are carried out through insulators in the roof for connection to the cable under test.

As an example of the kind of service given by this apparatus, a series of tests was made on a three-core cable, nine miles in length, designed for 22,000 volts working pressure, cross-sectional area of each conductor 0.06 sq. in. (39 sq. mm.) manufactured and laid by Standard Telephones and Cables, Ltd. The test van was drawn to a position at one end of the cable which happened to be out in the open country and three miles from the nearest source of electric supply. The testing-voltage was 75,000 volts between cores and 75,000 volts between cores and ground, for a period of 15 minutes on each conductor. Since the leakage current was 0.95 milliamperes through each Kenotron, the insulation resistance was about 40 megohms or an average of 350 megohms for each mile.

The following is a description of a few points which arose during the operation of the set:

Charging the Cable

When the A.C. voltage is switched in, there is a large charging current in the first few seconds, the magnitude being of the order of ten or twenty times the steady leakage current. In order to avoid a heavy rush of current, it is advisable to limit the initial A.C. voltage to about a third of that required to produce the final A.C. testing pressure, and to increase the pressure gradually. In this way the charge builds up to its correct value within two or three minutes without damaging either the apparatus or the cable.

Discharging the Cable

It is essential to avoid discharging the cable suddenly, such as by connecting an earthed wire to the conductors after disconnecting the A.C. supply, inasmuch as heavy surges are likely to be set up thereby, with consequent damage to the apparatus. In one case when sparking accidentally occurred between the high tension terminals, an oscillation which was set up was reproduced back on the low tension supply side, causing a violent spark-discharge on the slip rings of the alternator, accompanied by the explosion of various lamps connected thereto.

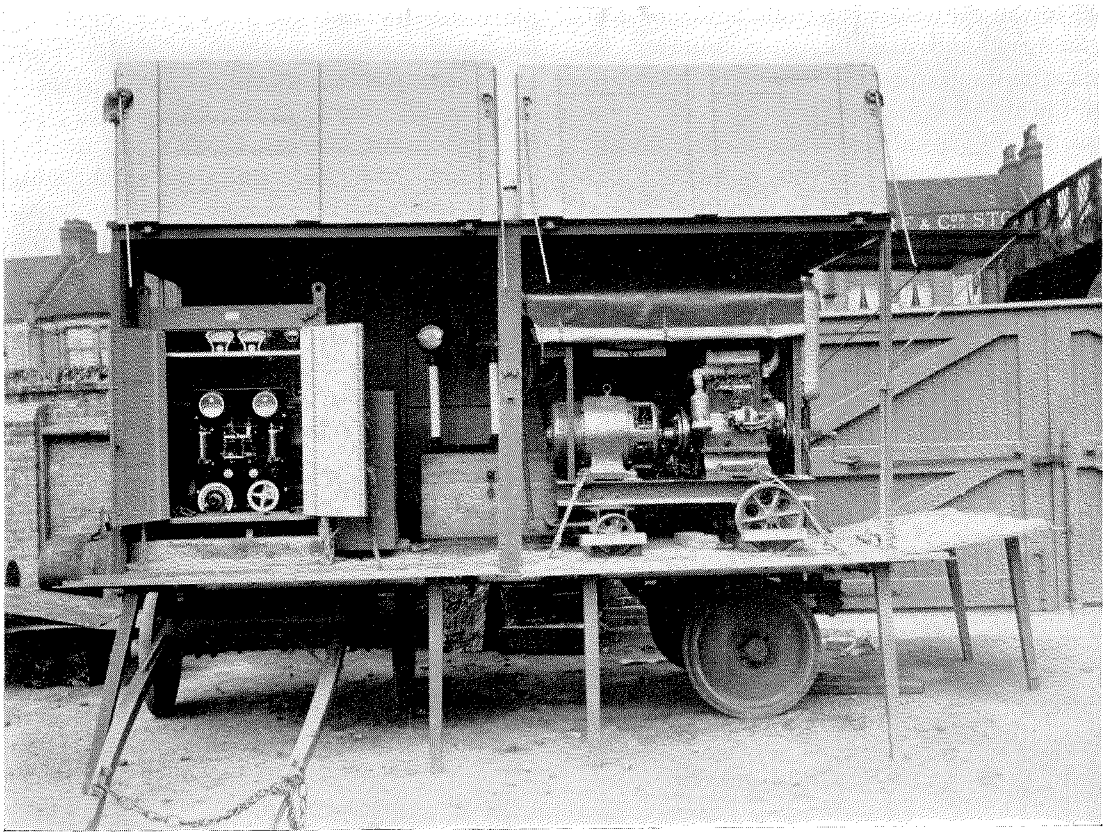

Figure 9—Portable Kenotron Set Assembled

It was thought that the sphere-gap voltmeter could be utilized for discharging the cable. A carbon pencil was attached to each sphere, so that when brought together the cable charge would be dissipated, in the case of a 75,000 volt test, at a maximum of .038 amperes. This method was followed successfully on many occasions; but, when discharging the nine miles of cable previously mentioned, an explosion occurred which disintegrated the carbon and its ebonite container, scattering the fragments to a distance of many feet. A simple calculation showed that the energy stored in the dielectric was

$$1/2\ CE^2 = 7{,}000 \text{ joules}$$
$$(C = 2.5 \text{ mfd.} \times 10^{-6}).$$

Assuming a discharge period as long as one second, the energy release occurred at an average rate of 14 kilowatts, which, of course, explains the carbon pencil explosion.

After this incident, it was found convenient to discharge the cable by utilizing a heavy wooden standard placed on the ground and bound with a copper wire at a height of three feet. An insulated handle was used to bring the wire in close proximity with the charged conductors, and thus to utilize the high resistance of the wooden standard to lead the current from the cable to ground. This freed the cable from the charge within two or three minutes.

When the first discharging operation has been completed, the short-circuiting wire must be retained for a considerable period. Its removal enables a voltage to build up, as the internal charges at the boundaries of the dielectric gradually disappear by conduction through the insulation. Steinmetz has treated these phenomena exhaustively [1] and an endeavor was made to correlate the observed results in the light of the theories advanced in his work.

[1] "Cable Charge and Discharge," Steinmetz, *Journal A. I. E. E.*, July, 1923.

Self Leakage of Charge on Cable

Figure 10 shows two curves taken on wet and dry days, respectively, in order to ascertain

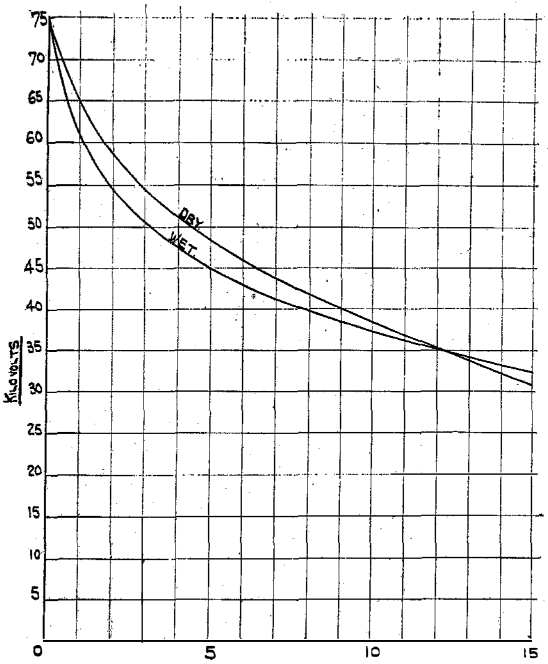

Figure 10—Self-discharge of Cable

how long the cable will retain its charge after removing the D.C. supply. Applying the old "insulation resistance by loss of charge" theories to these curves, results are calculated which do not agree with the known values of the insulation resistance, but when the experimental curves are analyzed with reference to the Steinmetz transients, entirely different results are obtained. The results given here cannot be regarded as highly accurate for the observations were not made in the first place for such an analysis and certain refinements may have been neglected when taking the measurements. It is of interest to record the figures, however, since they illustrate how a new avenue is opened up for study of the behavior of the dielectric under direct-current potentials, and for investigation of absorption and residual charge.

Figure 11 (A and B) show the exponential curves of the two transients which add up together to give the observed cable discharge curves of Figure 10.

Curve (A) $E = e_1 + e_2$

$$= 27500\epsilon^{-0.008050t} + 47500\epsilon^{-0.000398}$$

When $t = O$, $E = 75000$

Curve (B) $E = e_1 + e_2$

$$= 13780\epsilon^{-0.01217t} + 61220\epsilon^{-0.000786t}$$

The precise physical meaning of these figures has not yet been explained satisfactorily, but

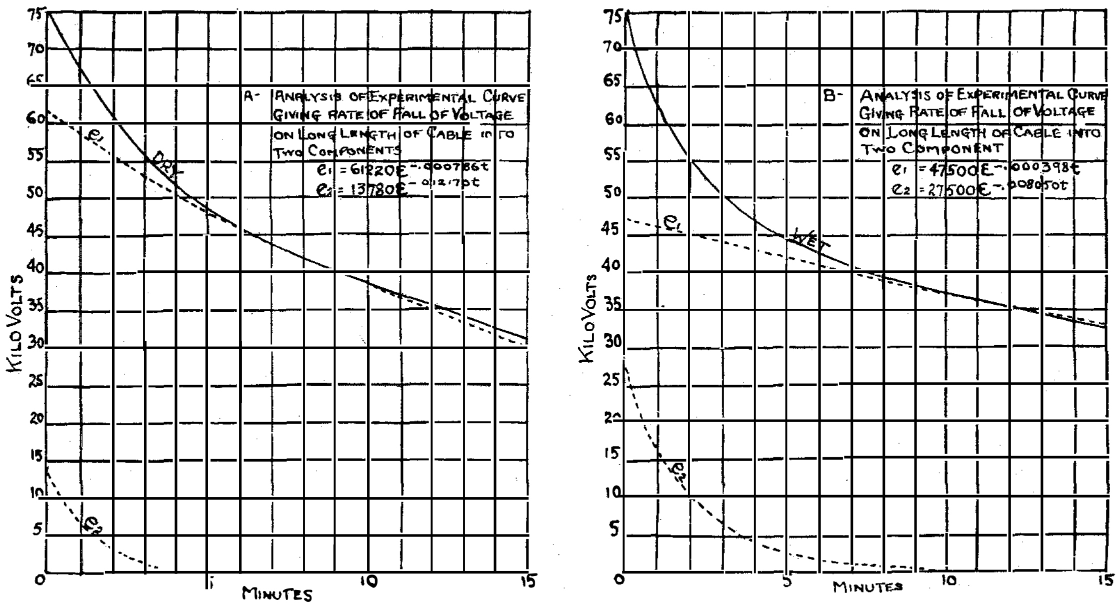

Figure 11—Analysis of Self-discharge

research work now in progress is expected to shed fresh light on this subject.

A more profitable line for further research is in connection with the analysis of D.C. charging current such as that shown in Figure 12 (A and B). Applying the Steinmetz transients we have:

Curve (A) $I = i_1 + i_2 + i_3$ microamperes.

$$= 1.000 + 0.88\epsilon^{-0.1625t} + 2.20\epsilon^{-1.0425t}$$

Curve (B) $I = i_1 + i_2 + i_3$ microamperes.

$$= 0.386 + 0.395\epsilon^{-0.171t} + 0.685\epsilon^{-1.095t}$$

It is seen that whereas the discharge curves of Figure 11 are the sum of two transients representing the leakage of the absorbed energy in the dielectric, the charging curves of Figure 12 are the sum of three transients. Current components i_2 and i_3 represent the absorption current into the dielectric and current i_1 obviously represents the true leakage current which will continue to flow after a steady state has been reached. We thus have a very simple way of comparing the true insulation resistances of different cables. The errors caused by measuring the absorption current in addition to the true leakage current, are eliminated by taking a series of readings of charging current, analyzing the resultant curve into its components, and so finding the steady leakage current i_1. Dividing i_1 into the applied e.m.f., e, gives the true insulation resistance e/i.

The previous method in which the leakage current was measured after one minute's electrification is thus shown to depend on the sum of three components, two of which are varying with time according to different exponential laws, and that method is therefore misleading when taken as a basis for comparing different cables.

Fault Location

The cable-maker's art has reached such a high degree of perfection that actual breakdowns are uncommon. Breakdowns such as do occur can often be traced directly to some mechanical damage either internal or from without, and it frequently happens that faults of this kind take many months to reveal themselves.

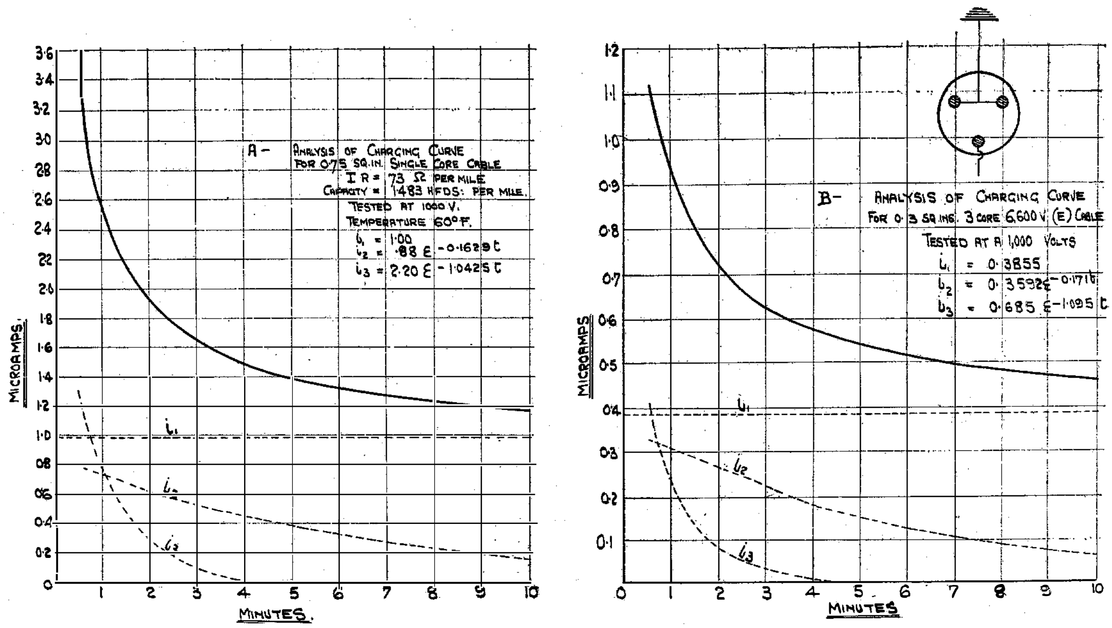

Figure 12—Analysis of Charge

Phelps and Tanzer [2] have shown how the Kenotron may be used for predicting breakdowns by making periodic tests and by observing the leakage current to the cable on a D.C. test.

Owing to the heavy dielectric thickness on supervolt cables, it happens almost invariably

[2] "A New Method for Positive Testing A.C. High Voltage Paper Insulated Cable by Kenotron," Phelps and Tanzer, *Jour. A. I. E. E.*, March, 1923.

that when faults develop, they are difficult to locate on account of their extremely high resistance. Thus it is possible for the installation engineer to be faced with the proposition of localizing a 20 megohm "fault" in a long length of ten miles, or more, of cable having an overall insulation resistance, when sound throughout, of 50 megohms, these figures being taken with the 1,000 volt megger. When the working or testing pressure is being applied, however, the fault is more definitely present and may for the case cited, reach 100,000 ohms or lower, thus demanding immediate localization and repair. When the cable is rendered "dead" again for the megger test, the fault resistance is found to have risen to 20 megohms once more.

For these high-resistance troubles, it is impossible to make use of the well known methods of fault localization, as the results are not accurate enough to warrant opening the ground and cutting the cable at the spot indicated.

As an example of the nature of high resistance faults which are encountered, consider the case of a joint which has "flashed over" owing to the ingress of moisture, incomplete compound filling, or other cause, during the integrity tests after installation. At the moment when breakdown occurs, the cable discharges its internal energy through the arc, thus reducing the testing-voltage to a low value for many seconds while recharging takes place. During this period an oil-flow may occur, carrying away the charred particles which constitute the path of the arc. The fault has thus vanished for a time, or even altogether. When the breakdown has been established finally, in the form of a long irregular chain of carbonized particles, its ohmic resistance is naturally high. There are then two courses open, either (a) the fault must be broken down to a low resistance value, or (b) it must be localized at the high resistance figure.

Use of Kenotron for Reducing Fault Resistance

In order to test the Kenotron set, to discover whether it is capable of being used to burn out a fault, a sample of twelve feet of 0.15 square inch (about 97 sq. mm.) three-core cable was experimented with in the laboratory. The insulation thickness was 0.20 inches (5.1 mm.) of paper between cores, and 0.20 inches (5.1 mm.) between the cores and the lead sheath. The cable withstood 130,000 volts D.C. for ten minutes without breaking down.

A pin was then driven into the lead and withdrawn; the pressure was again applied, whereupon arcing took place reducing the resistance from infinity to a few ohms in a quarter of an hour.

As the above experiment was not regarded as completely conclusive, since burning would naturally follow the arcing through the airspace formed by the pinhole, another test was made. A cut was made through the belt insulation and moisture was introduced. The 500 volt D.C. megger registered infinite resistance at this stage. Pressure was reapplied, and a breakdown took place at 130,000 volts D.C. The megger again indicated infinity and it was then considered that the conditions were identical with those which are encountered in the field; viz., high resistance with 500 volts D.C. but low resistance on the high-voltage test.

The cable was then closely wrapped with mica and black tape to prevent the presence of air and the formation of a flame at the faulty place. High-voltage D.C. was applied so that 0.080 amperes passed continuously for twenty minutes. At this stage the 500 volt megger registered zero insulation resistance. To verify this, a neon lamp in series with the fault was successfully lighted on a 220 volt circuit, and finally when high-voltage had again been used for five minutes it was possible to pass 0.0017 amperes with a four-volt battery, equivalent to a 2,400 ohm fault resistance.

The conclusion, consequently, was reached that the Kenotron set is capable of burning out a high resistance fault in a reasonably short period. Since the test was conducted on a short sample of cable, it was desirable to have a confirmation that faults on long lengths may be burnt out with equal facility. A subsequent test was carried out in connection with a recent contract for supervolt cables having an insulation thickness of 0.4 inch (10.2 mm.) of impregnated paper, when it was ascertained that a fault resistance equivalent to 50 megohms can be broken down to about 20,000 ohms within two to four hours, after which the ordinary localization tests may be applied with a reasonable degree of accuracy.

New Method of Fault Localization at High Tension

When localization tests are being made, it is often highly important that the results be obtained rapidly and hence the four hours expended in burning out must be eliminated.

Attempts have been made from time to time to carry out a loop-test at high-voltage by using a Delon apparatus instead of the usual battery. These failed because of the surges set up by the Delon set. The Kenotron set is not liable to voltage variations and surges.

The new method, which is in effect a Varley loop-test, was experimented with and successfully used in connection with the joint faults previously described. The connections, illus-

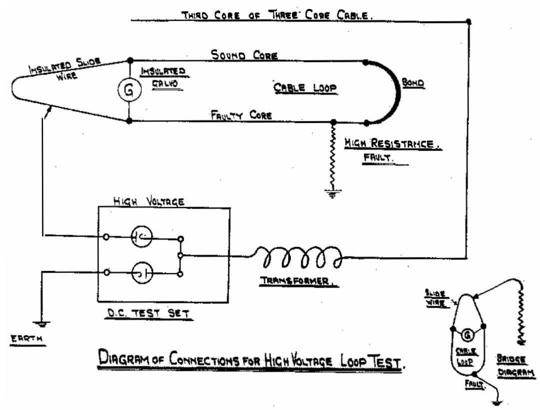

Figure 13—High-voltage Loop-test

trated in Figure 13, are very simple. Precautions for the safety of the testers are required. High-voltage D.C. is applied to the cable through the contact-hook on the slide wire, the galvanometer being connected across the free ends of the cable cores. The galvanometer is insulated on a porcelain stand. The slide wire is slung up in a convenient manner between strain type porcelain insulators. The contact to the slider is made through a hook on the end of a long insulated handle which enables the contact-point to be moved freely until a balance is indicated on the galvanometer. The calculations are then made in the usual manner to find the distance of the fault along the cable.

A single example will suffice to demonstrate the accuracy of the method. A fault appeared in a length of cable of 6,000 yards (5.5 km.), its resistance being 5 megohms on a megger-test and 50,000 ohms on high-voltage. The pressure at which the loop-test was conducted was 5,000 volts D.C., and localizations from opposite ends of the cable gave the following results:

Total length of cable....... 6,000 yards (5,486 metres).
Localize from one end,
1,566 yards (1,432 metres) from datum.
Localize from other end,
1,579 yards (1,444 metres) from datum.
True position = 1,566 yards (1,432 meters) from datum.
Maximum deviation from correct position expressed as percentage of total cable length = $\frac{(1579-1566)}{6,000}$ $+100\% = 0.2\%$.

Conclusions

The conclusions arrived at in connection with the testing of cables after laying with high-voltage direct-current may be summarized as follows:—

(a) A ratio DC/AC = 1.50 in breakdown-tests for cables is favored.

(b) The two-valve Kenotron portable high-voltage outfit can be used very efficiently and conveniently for applying D.C. integrity tests to cables after installation.

(c) The Delon type of apparatus produces transients, of such high-voltage as to cause very severe and possibly injurious stresses on the cable. The Kenotron type of test avoids these transients.

(d) The Kenotron outfit can be utilized for burning-out faults sufficiently to permit making accurate localization tests.

(e) The Kenotron can be used for a new high-voltage loop-test localization method for high resistance faults.

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