A Transmission System for Teletypewriter Exchange Service *

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A nationwide transmission system has been established in the United States for teletypewriter exchange service by means of which 2-way communication between teletypewriter subscribers can be established in a time comparable to that required for long distance telephone service. A brief description of the principle of operation of teletypewriters is included in this paper as an introduction to the discussion of the transmission requirements and the plan of the present system.

TO MEET the growing needs of business organizations, particularly those operating on a nationwide basis with branches at widely separated locations, there has developed in the United States an extensive use of private line telegraph service. This trend has been accelerated by the perfection of the teletypewriter, which makes it possible for regular office employees to transmit and receive communications without a large amount of special training. Some of these private line teletypewriter networks have been provided with switching facilities to permit the customer to set up connections between his various offices or groups of offices as desired. As these arrangements were perfected and as the public gained experience with the teletypewriter method of communication, a demand developed for a teletypewriter service in which all connections would be set up on a switched basis similar to that provided for spoken conversation by the telephone system. To meet this demand teletypewriter exchange service or as it is usually called, *TWX* service, was inaugurated by the Bell System in November 1931.

Briefly described, teletypewriter exchange service makes available to subscribers a complete communication system for the written word, consisting of:

(*a*) Teletypewriters for sending and receiving, installed on the customers' premises with a connection to a nearby switching center.
(*b*) Transmission channels interconnecting all of the switching centers.
(*c*) Teletypewriter switchboards for connecting the subscribers' stations and loops to each other or to the inter-city transmission channels and for making through connections between inter-city circuits.

This system provides for direct teletypewriter connections between the customers or their employees at the sending point and at the receiving points. The connection is two-way so that questions can

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be asked and answers given. The speed with which the connection is established is comparable to that experienced in long distance telephone service, the average being about 1.3 minutes from the time a subscriber calls the operator until the conversation between subscribers begins. The service has grown until at the present time there are over 8,500 * subscriber stations which may be connected together in pairs or in groups for teletypewriter communication. The switching is done at about 150 switching centers scattered throughout the United States as shown in Fig. 1 and connected by over 500,000 miles of telegraph circuit.

This paper deals primarily with the transmission system used for passing the teletypewriter code signals between the customers. The details of the switchboards and signaling facilities, and the methods of handling customers' connections are described in another paper.[1] With the exception of the switchboards, the equipment used in *TWX* service is similar to that used in other telegraph services.

The teletypewriters are provided with a keyboard similar to that of a typewriter for sending, and the typing is done in capital letters either on a narrow tape or on a page, the page being used in the large majority of the stations. Printed forms may be used on the page machines if desired. The speed of operation is set for a maximum of 60 words per minute. The teletypewriters are of the start-stop type, using a 5-unit selecting code, each group of selecting impulses being preceded by a start impulse and followed by a stop impulse. The teletypewriter mechanism is operated from a local source of power, and in general all signaling current is furnished from central office power plants.

The line circuits may be any of the well known types utilizing 2 current values or line conditions of variable duration for the transmission of signals. Actually about 90 per cent of the circuit mileage used in the *TWX* service is of the carrier type, since this is the most economical type of facility for large groups over the longer distances. The line circuits will be discussed in more detail in another section of the paper.

Elements of Teletypewriter Signal Transmitting and Receiving Mechanism

To translate intelligence which is received in the form of a code the receiving mechanism must be capable of doing two things. First, it must identify the unit time intervals, and second, it must determine which of the 2 line conditions should be recorded for each time interval.

* Since this paper was prepared the number of subscriber stations has increased to over 9,500.

[1] For all numbered references see list at end of paper.

Fig. 1—Map showing teletypewriter exchange service switching centers in the United States on April 1, 1936.

The first requisite is accomplished by maintaining a high degree of synchronism between the sending and receiving devices during the transmission of each character. The second is accomplished by providing satisfactory transmission facilities so that the mid-portion of each received signal element is the same as the corresponding signal element at the sending end.

Timing Arrangements

The sending and receiving devices are driven by motors which run at approximately the same speed. The receiving device is driven through a friction clutch so that it normally may be idle even though its motor is running. When a signal is received the receiving selector is released, makes one complete revolution, and again comes to rest. With this arrangement it is necessary to maintain synchronism only while one character is being transmitted, because a fresh start is made for each character, and the time intervals for the selecting impulses are measured from this starting point. Cumulative lack of synchronism, therefore, over long periods of time does not affect the accuracy of transmission. This is called the start-stop system.

The advantages of this arrangement are as follows:

(*a*) No elaborate means of synchronizing are required.
(*b*) The lag in the line is automatically taken care of because the receiving machine does not start until the first signal of a code combination is received.
(*c*) Multisection circuits and conference connections can be set up without any special line-up.
(*d*) Machines can be started and shut down without any special adjustment.
(*e*) Local power sources can be used for driving the subscriber's machine.

In actual practice speed is maintained within $\pm$ 0.75 per cent in either of two ways:

1. Where regulated frequency a-c. power is available, synchronous motors ordinarily will maintain the speed within ± 0.17 per cent, which is well within the limit necessary for satisfactory transmission.
2. Where regulated frequency a-c. power is not available, governed motors are used for either alternating or direct current. These governors are designed so as to maintain the speed within ± 0.75 per cent without attention over long periods of time. If the speed of the sending machine is out in one direction and that of the receiving machine in the opposite, the maximum difference may be 1.5 per cent.

Assuming no deformation of the wave shape between the sender and the receiver, the start-stop teletypewriter operating at 60 words per minute will stand about 7 per cent speed discrepancy before errors occur. In practice, however, there is deformation and therefore the speed discrepancy must be kept as low as practicable.

Sending and Receiving Arrangements

The sending arrangement in a teletypewriter is required to do three things:

1. It must transmit a signal which will start the selecting cycle of the distant machine.
2. It must apply the proper current condition to the line for each of the 5 accurately spaced selecting time intervals.
3. It must send a signal which will return the line to the normal idle condition.

The teletypewriter operates in a local circuit in which current is flowing during the normal idle condition. The transmitting is done by opening and closing this circuit, causing zero current or normal current in it, the two conditions being referred to as "open" and "closed." The selecting cycle of the distant machine is initiated by opening the circuit at the sending teletypewriter. This is called the "start" signal. The five selecting signals follow and the line current during each of these time intervals depends upon the character which is being transmitted. Since the normal idle condition of the line is closed, the "stop" signal which is sent last in the train of signals is a "closed" signal.

The selecting arrangement in a receiving teletypewriter is also required to do three things:

1. It must start timing the signals when the start signal is received.
2. It must determine the line condition at the midpoint of each selecting interval.
3. It must come to rest during the stop interval following the 5 selecting signals.

A single electromagnet in the receiving machine converts the electrical pulses into mechanical operations of the selecting mechanism. This magnet controls an armature which is energized for the closed line condition and de-energized during the open line condition. By this means the 2 line conditions are converted into 2 positions of the magnet armature.

Theory of Teletypewriter Signal Transmission

In teletypewriter signal transmission at 60 words per minute (hereafter called 60-speed) the start pulse and each of the 5 selecting signal elements are normally of 0.022 second duration. The minimum length of the stop pulse is 0.031 second. In keyboard sending the maximum length of stop pulse depends upon the time the operator hesitates between the striking of the individual keys of the teletypewriter. Any lengthening or shortening of the signal elements in transmission is referred to as distortion and is expressed as a percentage of the normal length of a signal element. The fundamentals of signal transmission have been discussed thoroughly by various writers.[2, 3, 4] A few of these principles are enumerated here without any attempt to discuss them thoroughly.

1. With the transmitting arrangements usually employed the complete change in line condition at the sender is practically instantaneous.

2. To transmit accurately these sudden changes in the line condition would require a transmission channel capable of passing an infinitely wide frequency band.

3. With a transmission channel which will pass only a limited band of frequencies there will be alteration of the wave shape during transmission as the result of changes in magnitude and phase of the various components caused by the characteristics of the transmission channel, so that changes in line condition at the receiving end will be gradual and in general displaced from their proper position.

4. Theoretically all of the intelligence can be carried by transmitting waves of a maximum frequency equal to that of the fundamental of the signaling speed considering the time interval of each signal element as a half cycle.

5. Actually it is not economical either to transmit a very wide band of frequency or to provide terminal apparatus capable of accurately recording the intelligence when only a band equal in width to the frequency of the fundamental of the signaling speed is transmitted. The arrangement used in practice must, therefore, be a compromise between these two extremes.

Experience has shown that in order to use economically practical types of receiving apparatus it is generally necessary to have present in the received signals a substantial portion of the second and third harmonics of the frequency of the shortest signal element, which requires in the case of 60-speed teletypewriter signals the transmission of a frequency band width of somewhat more than 45 cycles. To illustrate this a typical 60-speed teletypewriter signal is shown graphically in the upper left-hand diagram of Fig. 2. This diagram represents potential applied to the line for a perfect teletypewriter letter "D." At the instant when the start pulse commences, as described previously, the voltage applied to the line assumes its "open" value S, called "spacing." This spacing condition continues for 0.022 second at the end of which time the voltage suddenly assumes its "closed" value M, called "marking." The marking voltage remains constant through the first signaling pulse (1) in the figure. The second and third elements of the teletypewriter "D" signal are spacing and during these intervals the current is again of its spacing value. In the fourth pulse it once more becomes marking for 0.022 second, and in the fifth pulse it is again spacing. After the fifth pulse the current assumes its marking value for the duration of the stop signal.

This teletypewriter "D" signal may be further analyzed by considering it to be made up of sine wave components of various frequencies and magnitudes with certain definite phase relationships. It will be found theoretically to contain a number of sine waves of frequencies from zero to infinity. The left-hand column of Fig. 2 shows a number of the more important harmonic components of the "D" signal, the relative magnitudes and phase relationships being as indicated. The first is the d-c. component; the second is a sine wave of the same period as the over-all signal, and is referred to as the first harmonic. The wave shown in part *c* of the figure is twice the frequency of the over-all signal and is referred to as the second harmonic. Following this in turn are shown the third to tenth harmonics.

The right-hand portion of the same figure shows the synthesis of this signal from component parts. From this figure it may be seen that by the time the seventh harmonic (curve *q*) or even the fifth harmonic (curve *p*) has been added, there is a resemblance between the resultant and the original wave.

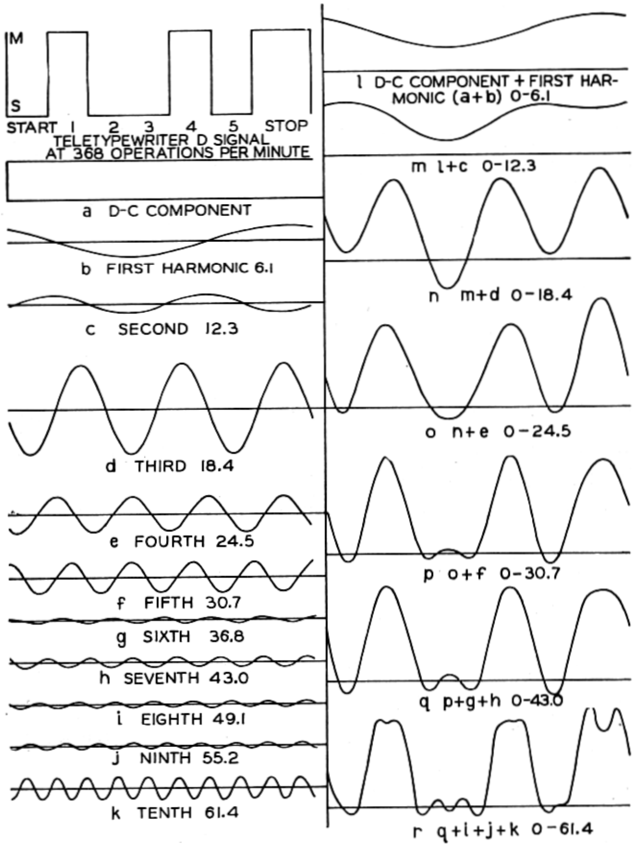

Fig. 2—Analysis of components of a teletypewriter "D" signal. Numbers on harmonic curves are frequencies in cycles per second.

As mentioned previously, the total intelligence transmitted by a given telegraph signal may be contained in a frequency band lying between zero and the fundamental frequency of the shortest signal element, i.e., the frequency at which the duration of the shortest element is a half cycle. In 60-speed teletypewriter transmission the shortest signal element is of approximately 0.022 second duration, and its fundamental frequency is about $1/0.044 = 22.7$ cycles per second. In the illustration in Fig. 2, this frequency would fall between that of curves *d* and *e* in the left-hand column and the character theoretically could be interpreted correctly with the transmission in correct phase relation of only the components up to and including the fourth harmonic (curve *o* in the right-hand column). As previously stated, however, while transmission of such a limited frequency range could be interpreted without error by an ideal receiving device, practical considerations of over-all economy make it desirable to transmit the wider frequency range mentioned.

Types of Distortion

In order to design a satisfactory teletypewriter transmission system it is desirable to understand the effects of various types of distortion and mechanical variations in the sending and receiving mechanisms. Figure 3 shows schematically that part of the receiving mechanism which is of interest in explaining the effect of signal distortion on correct interpretation of the message. This includes a receiving selector magnet with its associated armature and armature extension, a locking lever, a stop latch, and a selector cam driven by a friction clutch. In the idle condition the selector magnet is energized and the magnet armature and armature extension are in the position shown, the selector cam being held from rotating by the stop latch. When a train of impulses representing a character is received the start pulse (spacing) allows the armature and armature extension to move to a position shown by the dotted lines and at the same time releases the stop latch. This latter operation permits the selector cam to start rotating. The speed of rotation and the starting position of the selector cam are normally so adjusted that the first depression (shown by *A*) will arrive at the locking lever at the time the middle of the first selecting impulse is being received. The locking lever will then fall into this depression and the locking wedge *B* will move toward the armature extension and lock it in the position it occupies at this instant. This determines which of the 2 line conditions will be recorded for this signal element. Immediately thereafter mechanical arrangements (not shown) will operate to transfer this information to the selection storing mechanism. This process will then be repeated for each of the other 4 selecting impulses.

After the 5 selecting impulses have been received the slightly longer stop impulse is received. During the latter part of this impulse an arm *C* on the receiving selector cam will strike the stop latch and the cam will be held until the reception of the start impulse for the next character.

An orientation device or range finder is provided which rotates the stop latch with respect to the locking lever and thereby changes the time at which selection occurs with respect to the beginning of the selecting cycle. Moving the orientation range finder in effect moves the solid vertical lines in Fig. 3, with respect to the signal, and with perfect signals they can be moved by an amount corresponding to one unit impulse. In other words the time of selection can be moved by ± 50 per cent without typing errors, as shown at *a* in the figure. (In an actual machine this range is less because of practical con-

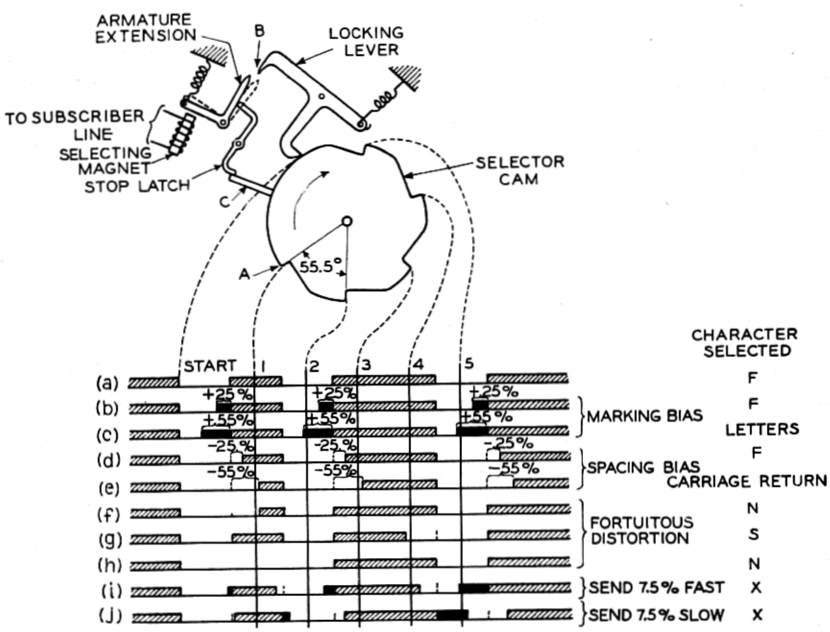

Fig. 3—Principles of selecting mechanism of a teletypewriter.

siderations of design, the time of selection being variable without errors over a range of about ± 40 per cent.)

Distortion in teletypewriter signals may be "bias," which is a uniform lengthening or shortening of all the marking impulses, or it may be of other types which affect only certain of the signal elements.[4] Bias is divided about equally between the ends of the impulse when the signal is received from the line. However, because the selecting mechanism starts rotating at the beginning of the start impulse, the effect of bias is to shift all impulses forward or backward with respect to this time. The result of this is that effectively there will be an addition to or subtraction from the front of each marking impulse, with the rear of the impulses remaining unchanged.

In an ideal machine where selection would be made instantaneously the signal would be recorded correctly if it had the right condition (i.e., marking if it should be marking or *vice versa*) at the instant of selection. The particular times when the selections take place with the orientation setting at the middle of the range with perfect signals are shown, as mentioned before, by the vertical solid lines numbered 1 to 5, inclusive, in Fig. 3. Referring to cases *b* and *d* it may be seen that with 25 per cent bias the correct signal is being received at the point of selection and it will be interpreted correctly. However, referring to cases *c* and *e* it may be seen that more than 50 per cent bias will cause errors. In case *c* the second and fifth impulses will be falsely interpreted as marking and in case *e* the first and third impulses will be spacing instead of marking. Several examples of the effect of distortion other than bias in the received signals are illustrated in cases, *f*, *g*, and *h* of Fig. 3.

The effect of variations in teletypewriter motor speeds on operating margins is illustrated in Fig. 3 by cases *i* and *j*. Case *i* shows the result if the sending machine is faster than the receiving machine. It will be noted that as the speed discrepancy becomes greater the first error will be a false mark for the fifth impulse because a part of the stop impulse is received on the fifth position. If perfect signals are assumed, the speeds would have to be somewhat more than 7 per cent different to cause errors of this kind in a normal teletypewriter with the range finder set in the middle of the range, but if there is some signal distortion other than that from speed discrepancies, such as marking bias, smaller differences in speed would be sufficient to cause errors. Case *j* illustrates the conditions when the sending distributor is slower than the receiving distributor. It will be observed in this case that the first error as the speed discrepancy increased would also be in the fifth impulse as the result of either the fourth impulse being sufficiently prolonged to fall on the fifth selecting position, or the fifth impulse being so late in starting that it is not properly received on the fifth position.

In the illustrations large speed discrepancies have been used so that the shift of the signals could be shown readily on a drawing.

General Transmission Design of *TWX* Network

Telegraph circuits comprising the transmission network employed in teletypewriter exchange service are laid out according to a fundamental plan similar to the toll switching plan [5] used in designing the toll telephone plant. The teletypewriter switching plan is designed to provide on the most economical basis the circuits necessary for satisfactory connection between any two stations in the country without any special line-up or adjustment of the circuits or apparatus.

Each switching point has a direct connection to each of the subscriber stations within its area (except for a few stations which are connected to the switchboards by a single channel carrier circuit operating over regular toll telephone circuits when a connection to these stations is desired). In addition it has direct toll circuits to one or more of the other switching points. Eight cities of considerable importance from the standpoint of switching in the national network are designated as "regional centers." These cities, New York, Atlanta, Chicago, St. Louis, Dallas, Denver, San Francisco, and Los Angeles, are interconnected largely by high grade direct circuits and ultimately will be interconnected completely by such facilities. Each of the regional centers has direct circuits to a number of smaller centers designated as "routing outlets" within a given area, which are also interconnected by direct circuits.

The other switching centers, called "teletypewriter centers," which are not required by their position in the networks to handle through business, have direct circuits to one or more routing outlets and may have direct connections to similar nearby centers if traffic justifies it.

The application of the teletypewriter switching plan is illustrated in Fig. 4. Considering only the toll circuits of the basic routes (solid lines connecting switching centers in the figure), it may be noted that within any area where the routing outlets are interconnected by direct circuits, the maximum number of teletypewriter toll lines required for connection between two stations in the area is 3. A very large percentage of the connections can, of course, be made with only one or two toll links. It may also be seen that, assuming all regional centers to be interconnected by direct circuits, a maximum of 5 toll links will serve to connect any two stations in the country, using only the basic routes.

In addition to these basic toll routes, supplementary routes are provided wherever the traffic warrants, as indicated by the dashed lines in the figure. These supplementary routes may be direct circuits between two teletypewriter centers, between a teletypewriter center and a routing outlet or regional center other than that through which it is normally served, or between a routing outlet in one area and a routing outlet or regional center in another regional area. It is obvious from the figure that the effect of these supplementary routes is to reduce the number of toll links and consequently the number of switches involved in certain connections.

The plan permits considerable flexibility with respect to arrangements for future expansion and changes, as growth can be taken care of by the provision of additional switching points or additional direct circuits with practically no change in the fundamental framework.

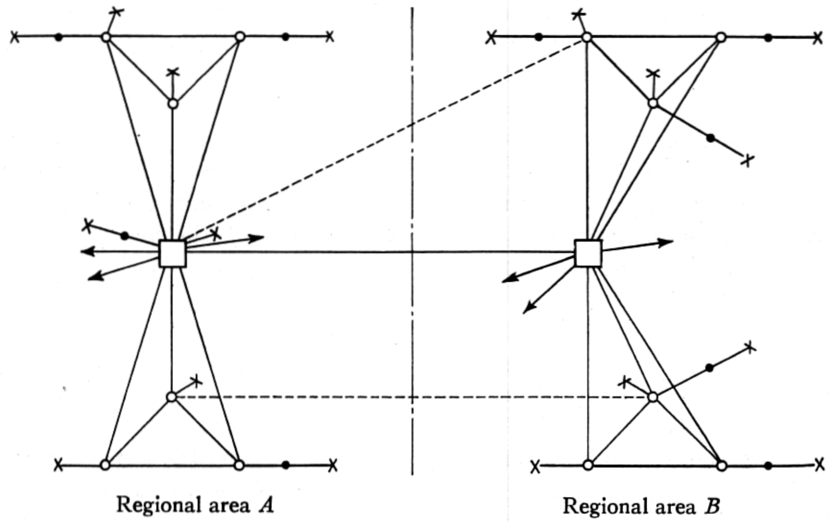

Fig. 4—Principle of application of teletypewriter switching plan.

□ Regional center
○ Routing outlet
● Teletype center
× Subscriber station
— Basic routes
- - Supplementary routes
→ Routes to other regional centers

Transmission Requirements

In the consideration of the transmission requirements the following items are of importance:

1. The over-all distortion on all connections must be low enough to permit satisfactory service.
2. The distortion on all of the links which will at times be part of built-up connections must be sufficiently low to permit satisfactory transmission when forming a part of such connections.
3. The distribution of distortion between the various toll links and between those links and the subscriber lines should be such as to obtain the desired transmission results with a minimum cost for the plant as a whole.

Transmission Coefficients

The transmission requirements of the over-all connection or of the individual elements are expressed in terms of a system of telegraph transmission coefficients which may be compared roughly to the system of net losses used in telephone transmission work.

In teletypewriter toll circuits of one or more sections the over-all distortion is made up of increments from a number of sources. Experience has shown that in general the over-all distortion of a particular signal element is equal to the algebraic sum of the individual increments. For each specific piece of equipment or element of the circuit the sign and value of the distortion cannot be predicted exactly as they depend upon facts which vary with individual cases. However, representative values of the maximum distortion experienced in a period of moderate length with miscellaneous signals for different types of circuit and equipment may be determined with fair accuracy. Experience and probability theory indicate that the most probable value of the over-all distortion of a telegraph circuit may be computed by taking the square root of the sum of the squares of the corresponding values for the various component parts of the circuit. With this as a basis coefficients have been established for individual telegraph circuits of the various types employed in the *TWX* transmission system. These coefficients are, in general, proportional to the square of the maximum distortion experienced with severe signal combinations under comparatively unfavorable conditions of circuit adjustment, weather conditions, etc., taking into account what is known about the general stability of the particular facility concerned. An estimate may then be made of the transmission impairment to be expected in service with a teletypewriter circuit made up of a number of sections of various types by adding the coefficients of the component parts. For convenience the value of the coefficients has been so chosen that satisfactory operation normally will be obtained over a connection if the sum of the transmission coefficients for the subscriber lines, switchboard circuits, and toll lines involved does not exceed 10.

Using these coefficients the entire transmission system is designed to provide satisfactory transmission between any two subscribers or combinations of subscribers. It is found that subscriber lines less than about 5 miles in length contribute little or no distortion to the over-all connections. Those up to about 35 miles may contribute distortion so as to warrant allowing a coefficient as high as 1.0 or 1.5, and for those up to 50 or 60 miles the coefficient may be as great as 3.5 or 4.0.

The following discussion assumes that the subscriber lines have a coefficient of not more than 1.0 or 1.5 from the subscriber station to the jack connected to the teletypewriter toll line at the switchboard, leaving for the toll links of the connection a maximum coefficient of about 7.0 or 8.0. In the case of intra-area connections involving 3 toll links, a permissible coefficient of 8.0 for all the links of the connections would, of course, permit a coefficient of about 2.7 for each link. Correspondingly, a connection involving 5 links would permit a coefficient of only 1.6 per link. It happens, however, that the transmission capabilities of the teletypewriter circuits generally in use are such that none of the circuits has a coefficient of less than 2.0 and that single sections of circuit may lie in the range of about 2.0 to 5.0. Practically, the availability of the higher grade circuits is limited by reasons of economy since, for example, the multi-channel carrier telegraph facilities which have coefficients of 2.0 to 2.6 would be too expensive to use for routes where only a few circuits are required or for the shorter links. It is apparent, therefore, that an over-all coefficient of 7.0 to 8.0 cannot be realized on either 4 or 5 link connections without some means for overcoming the over-all distortion. For these cases the operators are provided with connections to regenerative repeaters, which are inserted in series with the circuit and retransmit the teletypewriter signals exactly as they were originally

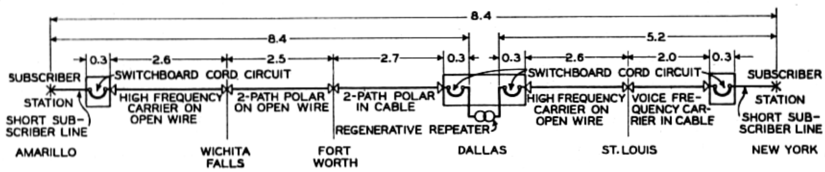

Fig. 5—Diagram of typical teletypewriter exchange service connection requiring regenerative repeater.
Numbers are transmission coefficients.

transmitted into the circuit at the sending end, provided they have not been distorted beyond the point where they can be correctly interpreted by the regenerative repeater. The latter has about the same signal distortion tolerance that a teletypewriter would have if the circuit terminated at that point. Thus the regenerative repeater wipes out the distortion of the preceding toll links and subscriber line so that the coefficient at its output will again be zero. The circuit layout for an actual connection is shown in Fig. 5 illustrating the use of a regenerative repeater.

For the purpose of the teletypewriter exchange circuit layout, it is assumed that regenerative repeaters are available at the switchboards of all regional centers so they may be used to handle 4 and 5-link connections. They are required occasionally at routing outlets to provide satisfactory over-all results on 3-link connections. In the case of 2-link connections the use of regenerative repeaters is ordinarily avoided by limiting the coefficient of the subscriber line, switchboard, and first toll circuit to 5.0. For subscriber lines on which it is not economical to provide facilities having coefficients as low as 1.5 the traffic routing instructions call for the use of additional regenerative repeaters at suitable points.

The types of telegraph facilities that are used for these various classes of toll link and subscriber line are discussed farther on.

Facilities Used in *TWX* Network—Teletypewriter Stations and Subscriber Lines

A typical teletypewriter station, illustrated in Fig. 6, includes the sending and receiving equipment, together with power supply, and supervisory equipment for initiating a call, informing the attendant of an incoming call, or recalling the switchboard operator during the progress of a connection if desired. These features are described in detail in the paper on switchboards and signaling facilities referred to previously.[1]

Any one of several types of teletypewriter subscriber lines may be used to connect a station with the switchboard from which it is served, the type chosen depending upon conditions in the particular case. A large majority of subscriber lines, however, consist of cable pairs used exclusively for that purpose. In these the telegraph method employed is one in which polar signals (a positive potential for spacing and a negative potential for marking pulses or *vice versa*) are impressed on the subscriber line by a telegraph repeater in the cord circuit at the central office, and neutral signals (the circuit closed for marking and opened for spacing) are transmitted by the sending contacts of the teletypewriter at the subscriber station.

The polar signals transmitted from the central office are symmetrical and the transmission quality of these signals is not affected seriously by the capacitance of the cable loop. As is ordinarily the case in duplex transmission, the current impulses are transmitted differentially through two windings of a relay in the cord circuit repeater which responds to incoming signals but not to the outgoing differentially transmitted signals. To prevent the undesired response of this relay to the outgoing signals, it is necessary that the differential winding not connected to the subscriber line be terminated to ground through an impedance similar to that of the subscriber line. Since subscriber lines from a given type of switchboard are all arranged to use the same current value the resistance component of the station line impedance may be balanced by fixed resistance.

With cable circuits of appreciable length, however, the capacitance becomes of importance. Up to a certain length the effect of the capacitance on balance can be minimized by locating a substantial portion of the current limiting resistance in series between the subscriber line jack at the switchboard and the subscriber line. For longer circuits an impedance modifying network consisting of capacitance, inductance, and resistance in parallel is inserted in series with the circuit between the subscriber line jack and the subscriber line. The constants of this network are so chosen that the subscriber line

Fig. 6—Typical teletypewriter subscriber station.

will be satisfactorily balanced by the same cord circuit repeater balancing arrangement that is used for the shorter subscriber lines in the office.

At the station the sending contacts and receiving relay or magnet are in series with the subscriber line. Signals from subscriber stations are formed simply by opening and closing the circuit at the sending contacts in accordance with the code for the characters being transmitted. When the contacts are closed a current flows in the subscriber line circuit for marking and when they are open this current becomes zero, transmitting a spacing signal.

On long cable pair subscriber line circuits with considerable bridged capacity, the wave shape of the current received in the central office is not symmetrical as regards the marking or spacing conditions, the rate of building up of the marking current being much faster than its rate of decay. This results in marking bias in the received signals. Conversely, in subscriber line circuits containing only series inductance and resistance, the received current builds up gradually to its marking value and decays to zero immediately when the sending contacts are opened for a space. By properly combining the inductance and capacitance, it is possible to produce substantially unbiased signals at the receiving end. In other words, by inserting series inductance in a cable circuit, it is possible to overcome the marking bias effect mentioned above so that practically no distortion occurs in the subscriber line.

The marking bias may also be reduced effectively by the use of series resistance in place of inductance at the subscriber station in cases where it is possible to add a sufficient amount of resistance without reducing the current below the desired value. The effect of series resistance used in this way is to delay the building up of the current when the teletypewriter sending contacts are closed after a spacing signal to compensate for the delay in decay of the received current after the contacts have opened.

Both of the above methods of reducing bias are in use in the present teletypewriter exchange plant. Figure 7 shows the wave shape of uniformly timed marks and spaces received over a 30-mile 19-gauge cable pair, illustrating the effect of the cable capacitance, and the manner in which a wave shaping arrangement, consisting primarily of inductance in this case, reduces the amount of marking bias in the received signal by retarding the building up of current at the start of each marking signal.

Although the majority of subscriber lines are in cables, it is sometimes necessary to serve stations at greater distances from the teletypewriter center or in situations where the use of cable pairs is not practicable. For these, other arrangements must be made. One method of serving such stations is by means of arrangements similar to those of the shorter toll circuits. Generally a telegraph repeater in an office in the vicinity of the subscriber station is used, and transmission between that repeater and the one in the teletypewriter center takes place in the same manner as over a toll circuit of similar length.

Another method for connecting to subscriber stations which cannot be cared for by a metallic cable pair employs a simple telegraph repeater installed as part of the subscriber station equipment. This arrangement as well as the one previously described has the advantage that it permits polar signals to be used in both directions over the subscriber line.

In a few cases which have arisen where telegraph facilities were not readily available between the teletypewriter center and a subscriber station, use has been made of a single-channel voice-frequency carrier

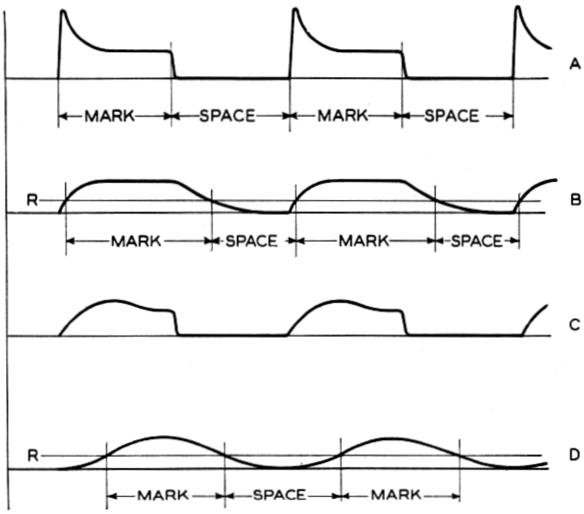

Fig. 7—Effect of wave shaping networks in long subscriber lines operated over cable pairs.

A—Current at subscriber station; no wave shaping network used.
B—Current in A as received at central office.
C—Current at subscriber station; loop equipped with wave shaping network.
D—Current received at central office; loop equipped with wave shaping network.
R—Current required to operate receiving relay of repeater in central office.

telegraph arrangement by means of which the transmission takes place over standard telephone circuits. A small carrier telegraph terminal arrangement is mounted on the back of the teletypewriter table, and a corresponding carrier terminal is located in the teletypewriter center in a trunk circuit between the teletypewriter switchboard and the telephone toll board. Special operating procedures are set up so that whenever the subscriber initiates a call, connection is established by telephone operators over telephone circuits to the above mentioned carrier trunk circuit at the teletypewriter center, and the teletypewriter switchboard operator is notified of the call and given the number of the subscriber by whom it is made. From the subscriber's standpoint calls are made with this equipment in practically the same manner as when ordinary telegraph facilities are employed.

Switchboards

The switchboards used in teletypewriter exchange service contain facilities for interconnecting subscriber lines, connecting them with toll circuits, or interconnecting toll circuits as required, together with the necessary means for establishing and supervising the connections. They are described in considerable detail in the previously referred to paper on switchboards and signaling facilities.[1] As indicated in the discussion of subscriber lines, the transmission circuit through the switchboard is essentially a differential duplex telegraph repeater. One such repeater is connected between the cords of each pair. This repeater is so designed that it introduces very little distortion in the connection. The coefficient of the switchboard cord circuit is 0.3. Figure 8 is a schematic diagram showing the principle of the transmission circuit.

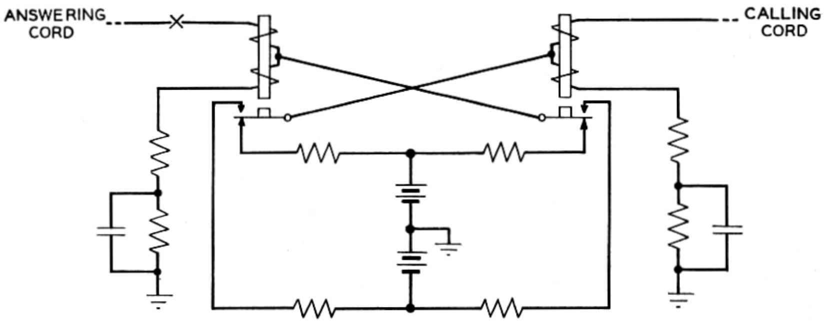

Fig. 8—Principle of switchboard transmission circuit.
Operator's teletypewriter inserted at × when required.

Toll Circuits

The toll circuits of the teletypewriter exchange network are of the standard types that are in general use for telegraph transmission. These include voice-frequency carrier telegraph systems on cable circuits[6] or on channels of carrier telephone circuits on open-wire lines, high-frequency carrier telegraph systems on open wires,[7] metallic systems on cables,[8] and two-path polar and differential-duplex grounded telegraph circuits.[9] An idea of the relative capabilities of these types of facilities may be obtained from Table I which shows the coefficients of a single section of each type.

TABLE I

TRANSMISSION COEFFICIENTS FOR 60-SPEED TELETYPEWRITER EXCHANGE CIRCUITS

Type of Circuit	Coefficient per section *	Maximum Section Length Normally Used, Miles
D-C. grounded system on open wire	2.5 to 4	300
D-C. metallic system on cable circuits	2 to 3	150
High frequency carrier system on open wire	2.6	1,150
Voice frequency carrier system on cable or open wire circuits	2.0 to 2.2	3,500

From the coefficients given in the table and the earlier discussion of the teletypewriter switching plan, it is apparent that the carrier systems, voice-frequency or high-frequency, where available, are most suitable for the longer backbone toll circuits of the nationwide network. For the short circuits of from 100 to 200 miles where cable plant is available, the metallic telegraph circuits on cable are extensively used, while for the scattering circuits of similar length, and most of the shorter toll circuits, use is made of two-path polar and differential duplex facilities. In some instances where single section facilities of the required grade are not available between two centers, regenerative repeaters permanently associated with multi-section circuits are used to provide satisfactory over-all circuits. Also in certain instances where circuits are not required for through switching, multi-section circuits without regenerative repeaters are sometimes provided and classified "for terminal purposes only."

All the components of the network—teletypewriters and their associated subscriber lines, transmission circuits in the switchboards, and toll circuits interconnecting the switchboards—are designed to give a satisfactory over-all transmission performance with a minimum cost for the plant as a whole. Results obtained in service indicate that the system is meeting a commercial need and that its performance is satisfactory, but developments are continually under way to effect further improvements in service and economies in operation as experience is gained with the system.

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* The term "section" as here used designates the part of a telegraph circuit between 2 telegraph repeaters or a section of a telegraph circuit without any intermediate telegraph repeaters. For example, a telegraph repeater section operated by the voice-frequency carrier telegraph method is that part of the circuit between carrier telegraph terminal sets, regardless of the number of intermediate telephone repeaters in the carrier circuit.

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