Carrier Systems on Long Distance Telephone Lines[1]

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SYNOPSIS: Two previous papers before the American Institute of Electrical Engineers discussed the activities of the Bell System in the development of multiplex telephone and telegraph systems using carrier current methods. The present paper describes developments which have resulted in improvements in the carrier telephone art during the past few years. A new, so-called type "C" system is described in detail, together with suitable repeaters and pilot channel apparatus for insuring the stability of operation; the line problems are considered and typical installations pictured. The growth of the application of carrier telephone systems and their increasingly important part in providing long distance telephone service on open-wire lines are shown.

INTRODUCTION

AT the 1921 Midwinter Convention of the American Institute of Electrical Engineers, Messrs. Colpitts and Blackwell presented a paper entitled "Carrier Current Telephony and Telegraphy." This described the development work of the Bell System and the resulting commercial types of multiplex telephone and telegraph systems using carrier current methods. The paper also gave a brief historical summary and included a theoretical discussion of the methods involved.

The carrier current art had at that time emerged from the laboratory to play its part in meeting the practical requirements of telephone service in the field. This step was made possible largely by two tools, now indispensable to the communication engineer, the thermionic tube and the wave filter.

In an ordinary telephone circuit, each frequency component in the voice of the speaker is transmitted by an electrical current of the same frequency. In most cases the electrical equipment of the circuit is not called upon to transmit frequencies above about 3,000 cycles per second. In carrier current operation, however, the voice-frequency currents are caused to modulate a high-frequency current which thus serves as a "carrier" for the message. In this way, an additional telephone channel is obtained, using frequencies entirely above those transmitted in connection with the ordinary voice frequency channel. By using other high frequencies, several additional messages may be transmitted simultaneously on the same pair of wires. Each channel occupies a certain range of high frequencies. For example, the words of one speaker may be conveyed by a channel employing frequencies from about 23,500 to about 26,000 cycles per

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[1] Presented before the Summer Convention of the American Institute of Electrical Engineers, June 29, 1928.

second. At the receiving terminal the various incoming ranges of high-frequency currents are separated by electrical filters. Then by demodulation the original voice-frequency currents are produced again and are transmitted over voice-frequency circuits, the transmission over each channel thus reaching the proper listener. In this way a telephone line already carrying direct-current telegraph and voice-frequency telephone services may be multiplexed so as to provide additional telephone facilities. In a somewhat similar manner the high-frequency range may be used instead to transmit telegraph messages. In the present paper, carrier telephony alone is considered.

The Colpitts-Blackwell paper described two carrier telephone systems which had been developed up to that time, a four-channel "carrier suppressed" system (type "A"), and a three-channel "carrier transmitted" system (type "B"). The initial installation of these systems was made about 1918 on the long lines of the Bell System.

These earlier systems were effective in bringing about economies by avoiding the stringing of additional wire on many long pole lines, but there remained many opportunities for further improvement in performance and simplification of equipment. New problems arose to be solved in connection with the desire to operate the largest possible number of systems on the same pole line. The result has been the development of a substantially improved technique and a new system (the type "C") which not only has provided much improved performance over its predecessors but which has led to further economies because of reduced costs.

Carrier Telephone Growth in Bell System. Whereas the use of the early types of systems was justified in competition with the alternative of additional wire stringing only for distances exceeding 250 to 300 miles, the new system proves economical for distances considerably less. This fact has naturally stimulated the application of carrier telephony in the Bell System. This is shown by Figure 1, which indicates the growth of these systems in terms of channel mileage afforded by their use. It will be noted that the rate of growth of the systems has increased greatly in the last two or three years, a result of the availability of the improved system.

At the end of 1927 there were in operation about 130,000 channel miles. By the end of 1928 the figure is expected to be about 230,000. This figure does not, of course, represent a very large proportion of the total toll mileage of the Bell System, which includes many circuits less than 100 miles in length. It is sufficient, however, to indicate that the carrier telephone systems are a substantial factor in the provision for the growth of the longer haul facilities, where they naturally provide the greatest economies. Their use is, of course, restricted to sections of the country in which open-wire construction is chiefly employed.[1] They have contributed toward lowering the cost of service and in making possible the toll rate reductions which have been put into effect within the past year or so.

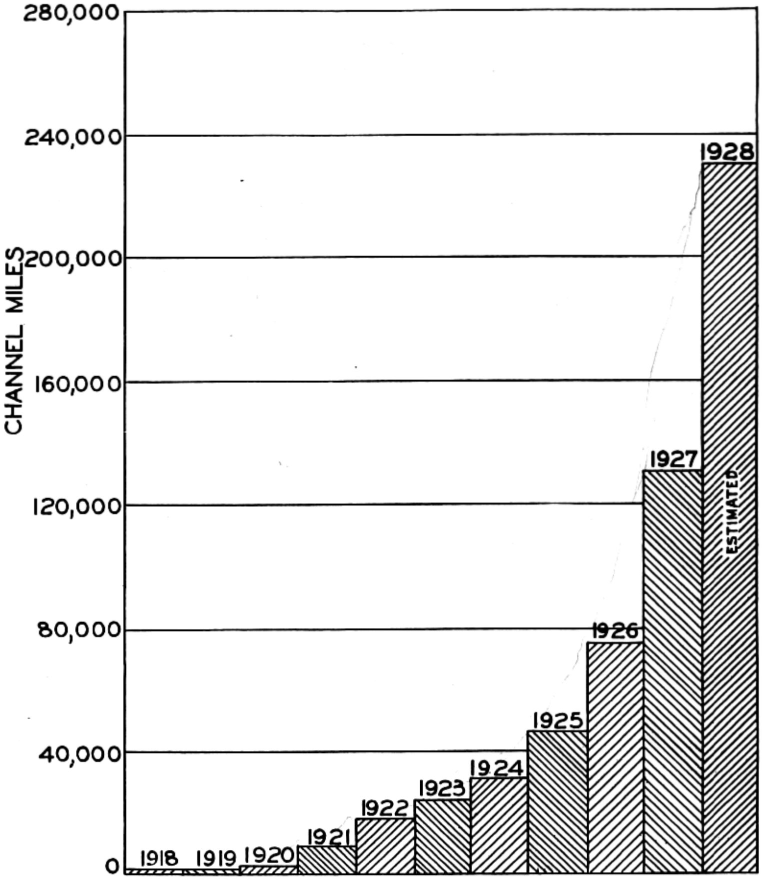

Figure 1—Growth of carrier telephony in Bell System

New System Replacing Older Types. The new type "C" system is essentially a long-haul, multi-channel system. It adds three high grade telephone circuits to the facilities normally afforded by a single pair of wires, and can be used over any distances likely to be encountered in the Bell System. Where repeaters are required they

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[1] In localities having very heavy traffic requirements such as in the East, extensive use is made of toll cables.

are spaced at intervals of 150 to 300 miles depending upon particular transmission considerations. By means of a pilot channel, stability of transmission over the several carrier channels is assured, despite the relatively large inherent variations in high-frequency line transmission due to weather changes.

The service requirements which present themselves in the application of carrier methods are, of course, basically no different from those for commercial talking circuits obtained by other means. The problem is to establish a toll circuit between long distance offices which meets certain standards of transmission, including speech volume, stability and quality. The latter requires that there must be transmitted a certain band width of frequencies in the voice range. Furthermore, there must exist no appreciable load distortion effects. The circuit must also be relatively free from noise or crosstalk. A signaling system must be provided so that the operators at opposite terminals may call each other. In other respects the system must appear as a normal telephone circuit not distinguishable from an operating standpoint from the other circuits afforded by metallic wire connections. The apparatus installed in the telephone office must conform to certain physical standards of equipment, ruggedness, flexibility, etc. It must be capable of being maintained by trained office forces. Testing facilities must be provided, etc. It is believed that these objectives have been largely realized in the arrangements which are described in this paper.

The Type "C" System

The type "C" system embodies those major technical features which our experience with the older systems has indicated as most desirable. It is a carrier-suppressed, single sideband system, in which respect it is similar to the older type "A" system. However, it has been found possible to dispense with the equal frequency spacing of the channels which was characteristic of the type "A" system, and which involved the transmission of a synchronizing current between two terminals and the harmonic generation of higher frequencies from this synchronizing current. A simplification in apparatus has resulted. This non-harmonic arrangement of channels has further made possible a more efficient use of the frequency spectrum by the fact that the channel bands at lower frequencies can be squeezed together more closely than those of the higher frequencies where the band filters are less efficient due to decreasing ratio of band width to frequency.

The type "C" system requires for each modulator an oscillator as a source of carrier supply. Moreover, since a synchronizing current is not employed at the receiving terminal of the channel, an oscillator of the same frequency is required for "demodulation." Advances in the art of designing vacuum tube oscillators of great frequency stability have made it possible to insure that these oscillators, which may be hundreds of miles apart, remain sufficiently close together in frequency so that no noticeable impairment in quality of transmission results.

In the matter of the frequency allocation of the channel bands, the type "C" system possesses one of the essential features of the older type "B" system, that is, the use of different carrier frequencies for transmission in opposite directions. Comparative experience with the type "A" system which, by means of high-frequency line and network balance, employed the same frequency band for the opposite directional paths of the channel led to the conclusion that the systems which avoided the high-frequency balance requirement were most desirable. Also the problem of intermediate repeater amplification is simplified where the opposite directional frequencies are thus separated and grouped. Furthermore, the crosstalk problem between different systems on the same pole line is greatly simplified for reasons which will be discussed later, and a greater total number of channels may usually be obtained on the same pole line.

The single sideband transmission employed reduces by about one half the frequency band that would otherwise be required for each channel. The carrier is not transmitted, as the presence in the system of carrier currents of the large magnitude required for a "carrier transmitted" system not only requires greater amplifier load capacity at the repeaters, but may increase the possibility of troublesome crosstalk and noise interference. The selectivity requirements of the band filters would also become more severe to keep the carrier of one channel out of the other channels in the system.

A Complete System. The simplified layout of a complete system is shown on Figure 2. It will be noted that it includes apparatus at a terminal, a line circuit, a repeater station, a second line circuit and apparatus at a second terminal. Obviously, the total line length between terminals may be extended by the use of a greater number of repeaters.

At each end there are the terminations of the three carrier channels 1, 2 and 3, and the regular voice circuit 4. These terminations appear, of course, at the long distance switchboard in the same office or in a different office from the carrier terminal. When a subscriber is connected to one of the terminations, for example, No. 1, speech currents pass through the three-winding hybrid coil, thence into the modulator circuit where they are caused to modulate high-frequency

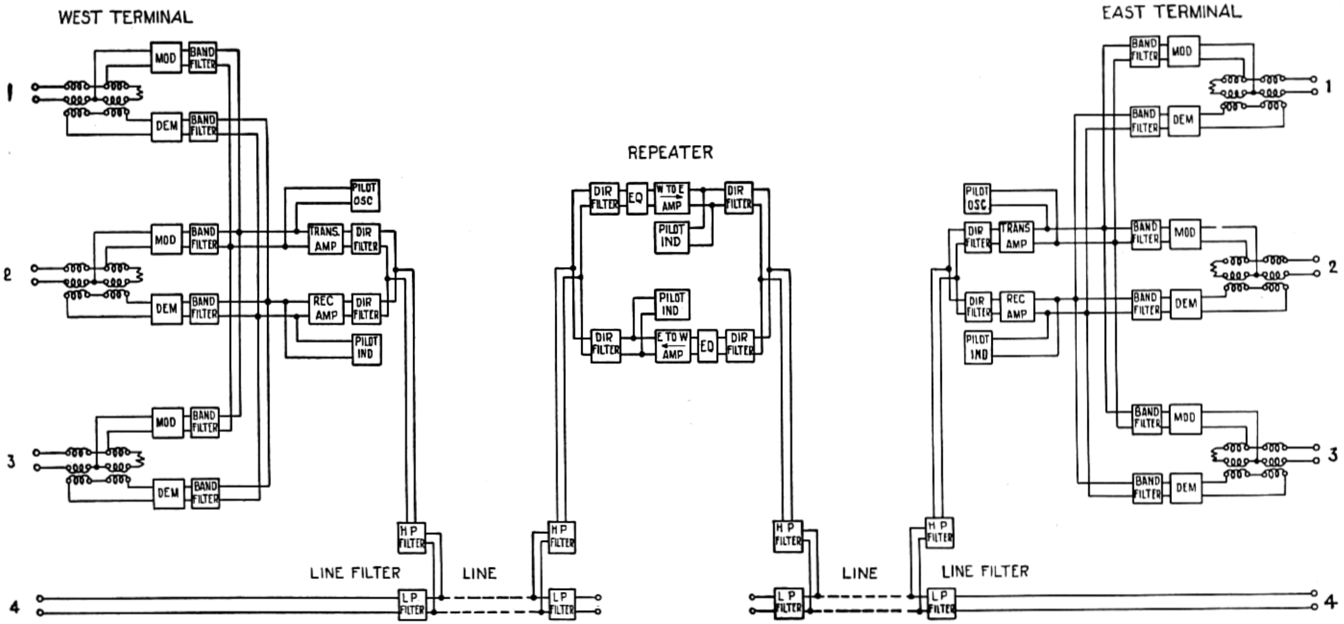

Figure 2—A complete carrier system schematic

carrier current. The resultant modulated bands [2] of frequencies pass through a band filter allowing only the desired band to pass to the transmitting amplifier, thence this band passes through a so-called directional filter and a high-pass filter to the line circuit. The high-pass filter last referred to, in association with its complementary low-pass filter, forms a so-called line filter set whereby the regular voice range currents are separated from the higher frequency carrier current at both terminal and repeater offices.

The other two carrier channels function similarly, and the several modulation bands of carrier frequencies join the first channel in passing through the common amplifier and directional filter circuit to the line. At the repeater point the group of bands comprising the three channels passes through the high-pass line filter circuit, thence through a directional filter and line equalizer to the amplifier circuit and outward through the directional and line filter circuit to the next line section. At the farther terminal the combined carrier currents pass through the directional filter and are again amplified in the receiving amplifier. At the output of the amplifier the different carrier channel bands of frequencies are selected one from another by the band filters, thence they pass to the demodulator circuit, are demodulated to their original form and then pass from the output connection of the hybrid coil to their respective terminations.

Circuit Arrangements at Terminals. Figure 3 shows diagrammatically in somewhat greater detail the terminal of the type "C" system. The modulator circuit consists of a two-tube "push-pull" grid-bias vacuum tube circuit in which the carrier frequency is balanced out. A separate oscillator tube circuit of exceptional frequency stability supplies the carrier. The frequency allocation requires the transmission of only the upper or lower sideband frequencies, and the band filter at the output selects the desired band, rejecting the other products of modulation as well as the amplified voice frequencies which are incidentally transmitted through the modulator unit. This sideband current in conjunction with the corresponding currents of the other two sidebands of the outgoing channels passes through the common amplifier. This is a two-stage vacuum tube unit having four tubes in the output circuit arranged in parallel push-pull connection to insure the required load carrying capacity.

The circuit then leads through a directional filter of either low-pass or high-pass type which distinguishes between the band groups of

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[2] For a discussion of modulation see E. H. Colpitts and O. B. Blackwell, "Carrier Current Telephony and Telegraphy," *A. I. E. E. Transactions*, V. 40, 1921, pp. 205–300; R. V. L. Hartley, "Relation of Carrier and Side Bands in Radio Transmission," *Bell System Tech. Jl.*, V. 2, April 1923, pp. 90–112.

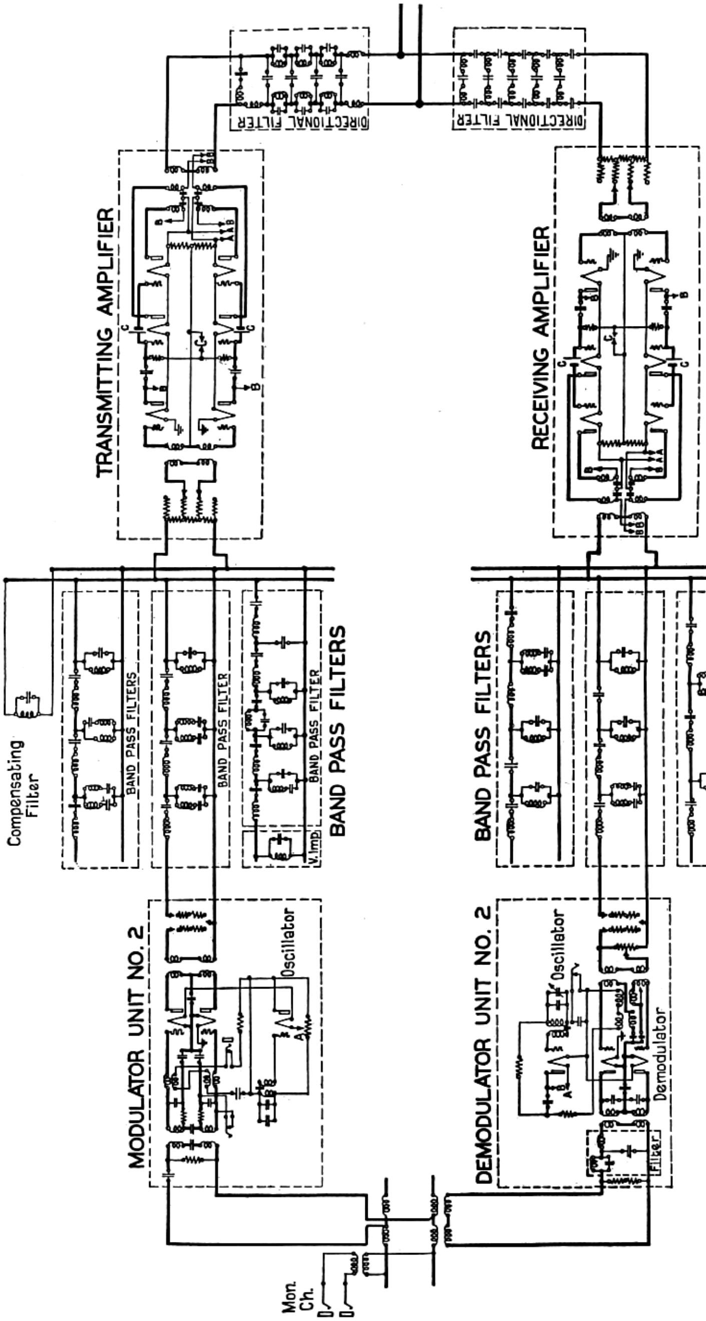

Figure 3—Schematic diagram of type "C" terminal circuit

the opposite directions of transmission as required by the allocation of frequencies. The amplified currents pass through the high-pass filter of the line filter set and thence to the line circuit.

In receiving, the sideband frequencies, after separation from the voice currents by the line filter set, pass through the directional filter and an amplifier similar to that used at the transmitting terminal. While the power output required at the receiving amplifier is usually small as compared to that required at the transmitting amplifier, the same unit is used for the two positions to provide flexibility in the adjustments of the receiving gains of the separate channels and for the purpose of economy in production. The different channel currents in the output of the amplifier are selected by the respective receiving band filters and thence pass into the demodulator circuits. In the demodulators the voice frequencies are derived by the modulation of the sideband currents with a carrier frequency supplied by a local oscillator whose frequency is adjusted accurately to agree with that of the corresponding transmitting modulator at the farther terminal. This important problem of synchronization of oscillators is further discussed later in the paper. It is, of course, obvious that if the carrier frequencies of the modulator and the corresponding demodulator of the same channel are not in sufficiently close agreement there will be a serious distortion of the speech currents received over the channel.

The output of the demodulator circuit includes a low-pass filter for suppressing the unwanted components of demodulation, and the circuit thence leads to the channel terminal through the hybrid coil. The function of the latter is to provide a two-wire termination of the channel and it prevents the output currents of the demodulator from reaching in any substantial magnitude the input of the modulator circuit, thus setting up a regenerative action which might result in "singing."

It may be noted that the circuit normally provides for a transmission "gain" or amplification of energy from the switchboard termination to the high-frequency line circuit of approximately 20 TU[3] corresponding to a current or voltage amplification of 10 to 1. In the receiving direction a gain of the same order of magnitude is also available. Of course, the exact amount utilized in a particular case depends on the line attenuation and the desired overall equivalent of the circuit. It is usually desirable at the transmitting terminal to maintain the level at the maximum possible for the system. The

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[3] R. V. L. Hartley, "The Transmission Unit," *Electrical Communication*, V. 3, No. 1, July 1924, pp. 34–42. W. H. Martin, "Transmission Unit and Telephone Transmission Reference Systems," *A. I. E. E. Jl.*, V. 43, No. 6, June 1924, pp. 504–507, *Bell System Tech. Jl.*, V. 3, July 1924, pp. 400–408.

overall transmission afforded by a carrier system may be noted by the curve on Figure 4, which shows the relative speech frequency transmission characteristics of a typical channel. Where the carrier channel is employed for terminal to terminal business the overall equivalent at 1,000 cycles is ordinarily adjusted to about 10 TU. The channels not infrequently form sections of much longer overall circuits, being connected to cable or perhaps open-wire circuits, in which case it is rather common to adjust the carrier section to a zero equivalent or even a gain of several TU.

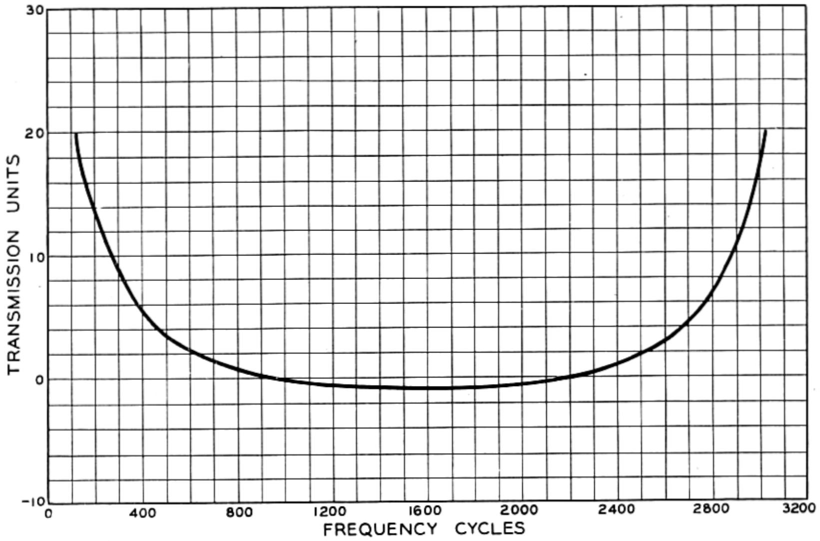

Figure 4—Representative overall transmission-frequency characteristic—type "C" carrier telephone system

Line Considerations. The passage of the carrier currents from the terminal apparatus over the line circuit which serves to connect the two terminals, or a terminal and repeater station, gives rise to several problems: the line loss or attenuation, the stability of transmission, the possibilities of crosstalk from other carrier systems on the same pole line and interference from currents from external sources. These factors must be considered not only in connection with the arrangement of the wires themselves but also in conjunction with the design of the terminal apparatus, repeaters, etc., so that satisfactory overall speech transmission may result.

As was brought out in the Colpitts-Blackwell paper, the line attenuation at the high frequencies is in accord with the recognized transmission theory. Because of skin effect in the wires and rising losses in the insulators the attenuation increases steadily with frequency. Unfortunately the losses at the insulators are not constant and they increase greatly with the presence of moisture. This brings about an increase in attenuation in rainy weather. Fog, sleet and wet snow may greatly increase these attenuation changes. There is also a lesser source of variation due to temperature change and its effect on wire resistance.

If care is not observed, the carrier currents may be interfered with on the line circuits by crosstalk from other carrier systems and by miscellaneous currents which enter the circuit by induction from the outside. These latter manifest themselves as noise in the carrier channels. This makes it essential to use only the metallic circuit, i.e., two wires well balanced to ground for transmitting the carrier currents. The balance to ground must be maintained at a high degree by frequent transpositions in the wires. Even with these precautions unavoidable residual unbalances may permit a certain amount of interference to appear. The final remedy is to insure that the relations between the circuit length and the apparatus gains are properly considered in order that the speech currents may have ample margin above the noise currents at all points in the circuit.

In the matter of crosstalk between systems closely adjacent on the same line the situation is alleviated by providing two frequency allocations. (See Figure 5.) These are "staggered" with respect to each other, so that a system installed on one pair using the so-called "N" frequency allocation has less crosstalk to and from a system installed and operating on an adjacent pair and using the so-called "S" frequency allocation than would be the case if both systems employed the same allocation. The maximum upper frequency required is raised only slightly by this arrangement.

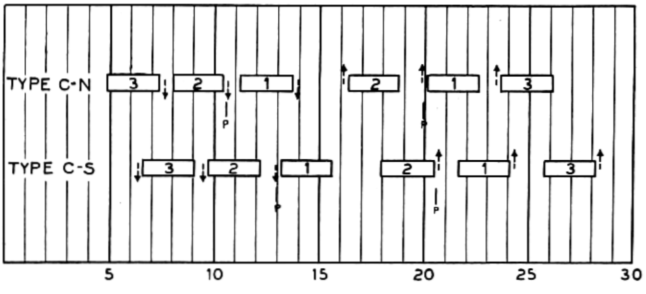

Figure 5—Frequency allocations of type "C" system

Repeaters. Repeaters must be employed when the distance exceeds that for which terminal transmitting apparatus is effective in maintaining the transmission level well above the line noise. The function of the repeater is, therefore, to amplify the carrier currents so that they pass on to the succeeding line section at a magnitude comparable to that sent out from the terminals. Obviously, the design of the repeater with respect to its gain and level carrying capacity, etc., presents a wide range of possibilities depending on the distance of transmission, frequency, etc.

It has been found most practical to install the repeaters along the route at approximately the spacing of the voice-frequency repeaters on the same wires. This means a spacing of from 150 to 300 miles, and occasionally slightly over 300. To have in the same office both voice-frequency and carrier repeaters reduces the equipment, simplifies the maintenance problem, and makes it possible to use the same sources of power supply. The gain and the load carrying capacity are, therefore, determined by this spacing, the gain being controlled by the attenuation loss between the repeaters, and the load carrying capacity by the output level desired because of noise considerations.

The higher attenuation of the line in the carrier range of frequencies means that the carrier repeaters must have a maximum gain of approximately four times that of the voice repeaters operated on the same wires. Whereas gains of the order of 8 to 15 TU may be readily supplied by voice repeaters using balance and so-called "two-wire" operation, the 30 to 45 TU gain required by the carrier repeaters necessitates non-balanced or "four-wire" operation or its equivalent, by using different frequencies in opposite directions and directional filters for the prevention of "singing."

Figure 6 is a schematic diagram of the circuits comprising a typical repeater station including loading, compositing apparatus and line filters. After passing through the high-pass line filter the carrier currents arrive at the high and low group directional filters which distinguish between the oppositely directed currents. These filters are substantially the same as those used for similar purposes at the terminal stations.

It is, of course, required in the design of the directional filters that in each direction the filters must pass a frequency band sufficient to transmit properly the three carrier channel bands. In addition to this the filters must present a loss outside of the transmission band which is sufficient to prevent the two-way amplifier circuit from "singing." This means that considering the closed loop circuit of the two amplifiers and the four directional filters the attenuation in this loop must be considerably greater than the sum of the gains or

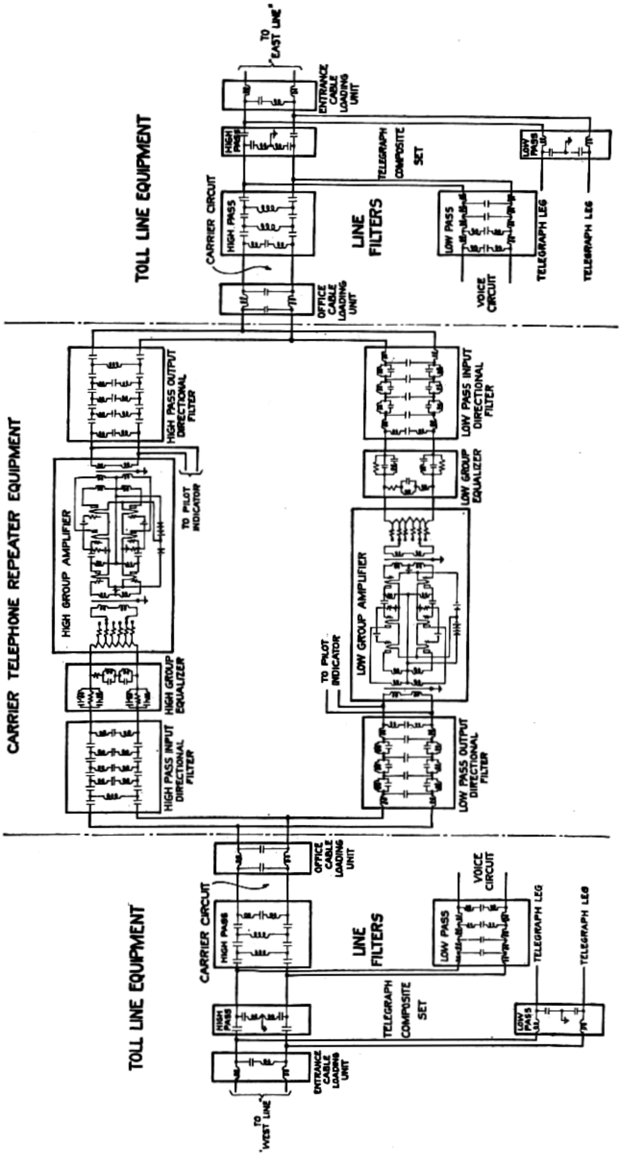

Figure 6—General schematic of carrier repeater circuit with associated line equipment

amplification of the two amplifiers. There are also other requirements which these filters must meet which are discussed later.

The amplifiers are the same as used for group amplification purposes at the terminals. Each consists of a two-stage reactance-coupled vacuum tube circuit having four tubes in parallel push-pull connection in the output circuit. The carrying capacity of this amplifier with the standard plate voltages is about one watt in the output, and the overall amplification or gain including incidental filter losses is about 30 TU. Where gains greater than 30 TU are necessary in the higher frequency group provision is made for the addition of an amplifier stage ahead of the unit shown, which adds approximately 15 TU gain. At the same time provision is made for the addition of greater directional filter selectivity.

An important feature of the repeater circuit is the equalizer which is connected ahead of the amplifier. Because the line circuit attenuation varies with frequency and is greatest at the higher frequencies it is necessary that the amplification introduced at a repeater point be varied with frequency. The amplification introduced by the amplifier unit itself is substantially uniform with frequency. The equalizer network, however, by introducing a loss which is a minimum at the highest frequency of transmission and which increases for the lower frequencies makes the overall repeater amplification a function of frequency and in general proportional to the line attenuation which it is designed to overcome.

A typical overall gain characteristic of the repeater is shown in Figure 7. The adjustment of the exact amount of gain desired at any time is made by the potentiometer at the input of the amplifier.

Pilot Channel. As noted previously, the attenuation of open-wire circuits of substantial length is affected by weather conditions. This makes it necessary to make occasional gain adjustments throughout the system. The extent of these adjustments is determined by means of the pilot channel, which provides a visual indication of the transmission levels of the carrier system in both directions of transmission without interfering with the speech currents over the channels themselves. It is, in effect, a separate constant frequency carrier channel allocated between certain speech channels in each transmission group.

The operation of the pilot is relatively simple. At each repeater point and receiving terminal there appears a meter for registering the output level of the amplifier. The pointer of the meter is expected normally to rest on the zero or normal level layout of the system. If a change in the attenuation of the line circuit causes a departure in the transmission level, the meter reading shows a corresponding "up" or "down" indication and by adjustments of the repeater or terminal amplifier potentiometers the level may be returned to normal. An alarm circuit is furthermore provided at the receiving terminal so that when the level has departed by more than a predetermined amount, say ± 1.5 TU, from the desired normal, the operating attendant is called in to make the adjustment.

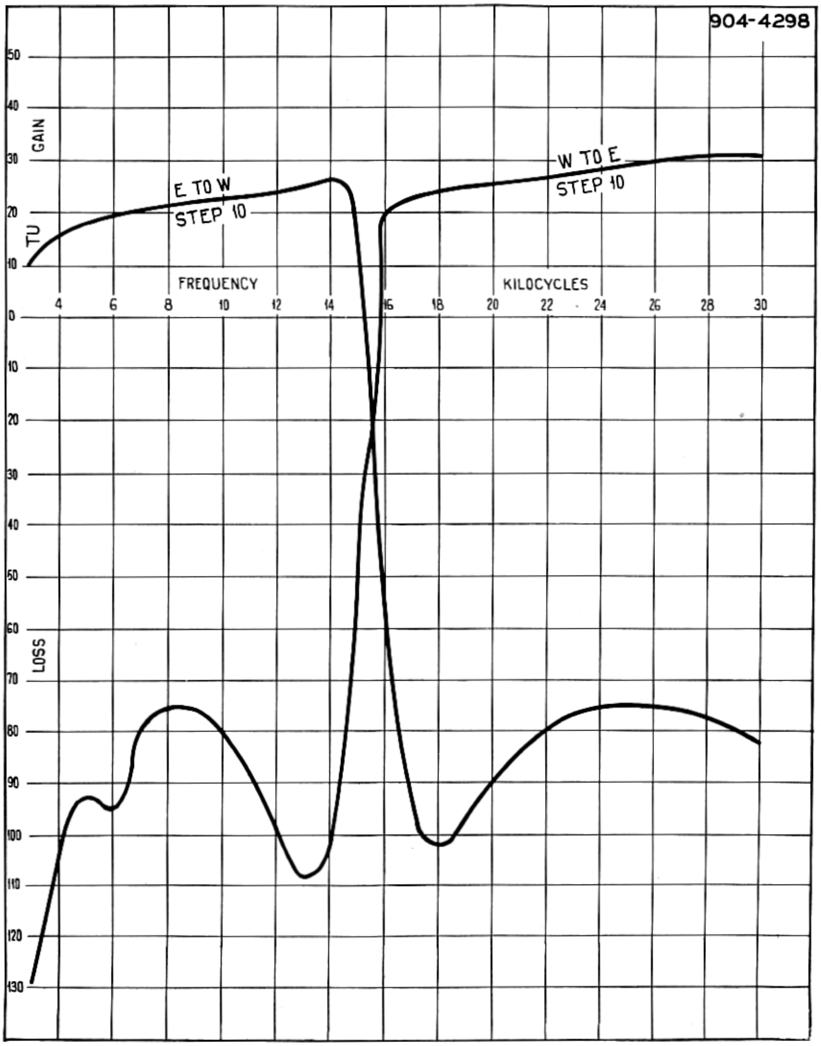

Figure 7—Overall transmission characteristics of carrier telephone repeater station

A high-frequency current of constant amplitude is transmitted from each end, and the meter indications are measurements of this current at the output of repeater amplifiers, and at the receiving terminal amplifiers (see Figure 2). A separate pilot frequency is utilized for each direction of transmission. Because no communication is carried on over this pilot carrier current, the band provided is extremely narrow, and no appreciable portion of the frequency spectrum is sacrificed.

The frequency selected for the pilot channel must coördinate with the other carrier system frequencies. The two frequency allocations of the type "C" system require different pilot channel frequencies, because their speech channels occupy different frequency bands. The apparatus has, therefore, been made so that the frequency of the pilot current can be adjusted to any value desired in the carrier range. The frequency selected for a given system may be determined by local conditions of crosstalk or interference, although in general the preferable location is between the channel bands as noted in Figure 5. The amount of current which is used is limited by its interfering effect into adjacent channels or into other carrier systems on the same line, and it is ordinarily of a low value, of the order of 2 to 6 milliamperes on the line.

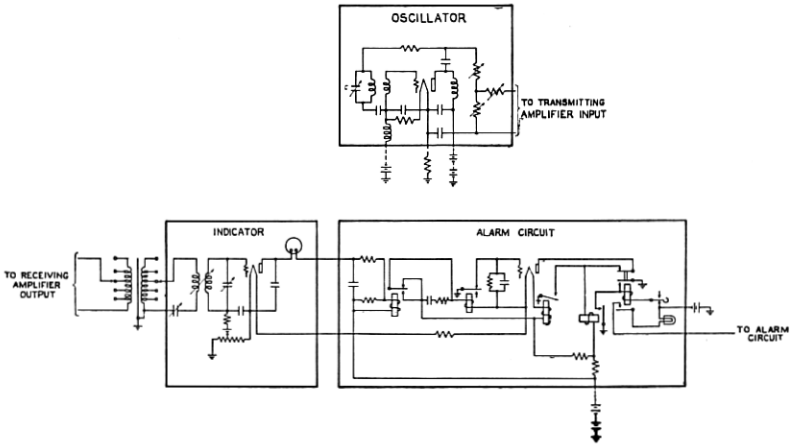

Figure 8—Schematic of pilot channel circuits. (The alarm circuit is used with terminals only)

Figure 8 shows schematically the principal features of the terminal pilot-channel circuit as a whole. The oscillator at each transmitting terminal which produces the pilot current is connected to the carrier circuit at the input to the transmitting amplifier, in parallel with the band filters. This current is amplified with the speech currents and transmitted through the directional filter to the line. The attenuated pilot and sideband currents pass from the first section of the line into the receiving directional filter of the first repeater and enter the amplifier. The pilot channel indicator circuit is bridged across the output of the amplifier, and is tuned to discriminate very sharply against all but current of the pilot frequency. This circuit has a high impedance relative to the line, so that only a very small percentage of the pilot current is drawn from the line at a repeater point. The remainder is transmitted through the outgoing directional filter and over the subsequent section of the line.

That portion of the pilot current which enters the indicator circuit is amplified and rectified in the vacuum tube detector, and the output current is read on a d.-c. milliammeter. As stated above, this meter is calibrated to read in TU above and below a mid-scale position which represents a normal transmission level to which the system is initially adjusted.

Entering the receiving terminal of the carrier system, the pilot and speech currents pass through the directional filter and are amplified. As at the repeater, the pilot indicator circuit is bridged across the output of the amplifier. At this terminal, in addition to showing level, the output of the indicator actuates an alarm circuit which operates when the transmission level at this point varies from normal for a set interval of time by more than a prescribed amount. This delay action in the operation of the alarm provides selectivity against slight interference into the pilot channel from currents on the other channels of the system and thereby insures that the alarm indicates a definite level change.

The pilot channel thus insures that the high-frequency portion of the system is continuously checked with the exception of the individual channel band filters and modulator and demodulator units. These, however, are particularly stable in operation and require no unusual attention in maintenance. Of course, the overall check is made at only the pilot frequency in each direction. Variations of line equivalent caused by weather changes increase in magnitude with frequency. Therefore, corrections must be made in the gain relations of the individual channels whenever these weather changes are great. Fortunately the corrections follow a fairly definite relation with variations of pilot level and are ordinarily made by the terminal attendants on the channel potentiometers controlling the demodulator gain by reference to a table. This table shows the relations between the required gain changes at the three channel frequencies in terms of changes at the pilot frequency.

The type of oscillator is essentially the same as that used in the type "C" carrier systems for producing the carrier frequencies. It is controlled by condensers which include an adjustable air condenser for tuning to the particular frequency desired.

Two indicators are located at the repeater, one for each direction of transmission. Each indicator circuit consists of a vacuum tube rectifier operating from coupled tuned circuits into a d.-c. milliammeter having a special scale calibrated in transmission units. The filament and plate currents and bias potentials are obtained from the standard 130-volt battery. The advantage of using the same battery for the several functions is that it makes possible the stabilization of the rectifier output with power variations. An adjustable grid bias voltage is obtained from the negative drop of the filament circuit with an opposing 3-volt dry cell battery connected in series. With this arrangement normal variations in the 130-volt source cause only a negligible change in the indicator meter readings.

At the receiving terminal, in addition to the indicator circuit which is the same as at the repeater, an alarm circuit is provided as noted above. A sensitive marginal relay is connected in series with the indicator meter. When this relay operates, it starts the delay circuit by removing ground from the grid condensers of the alarm tube. The leakage through the grid resistances then causes the condenser potential, which is the grid potential of an auxiliary rectifier tube operating from the same power source, to decrease slowly, resulting eventually in a rise in the current of the plate circuit of the alarm rectifier tube. If the marginal relay remains operated for a given length of time, the alarm tube plate current will rise to a value necessary to operate the alarm relays. For shorter periods of operation, the normal highly negative grid potential of the rectifier tube is restored and no alarm is operated. The timing of the delay circuit is adjusted by the values of the grid leak resistances and condensers. A delay of about 15 seconds is usually employed, which effectually prevents false operation due to occasional transients such as speech interference. The adjustment of the contacts on the alarm relay is ordinarily such as to cause an alarm to be given at limits of ± 1.5 TU variation.

General Transmission Considerations

Lines. The typical open-wire telephone line consists of a number of 10-foot crossarms spaced two feet apart on poles whose height varies from 30 feet upward depending on local conditions. The poles are spaced at an average interval of 130 feet. Each crossarm carries 10 wires. The wires are normally spaced at 12-inch intervals, except in the case of the so-called pole-pairs which straddle the pole and whose wires are about 18 inches apart. (See Figure 9.) The construction includes pins and glass insulators for supporting the wires.

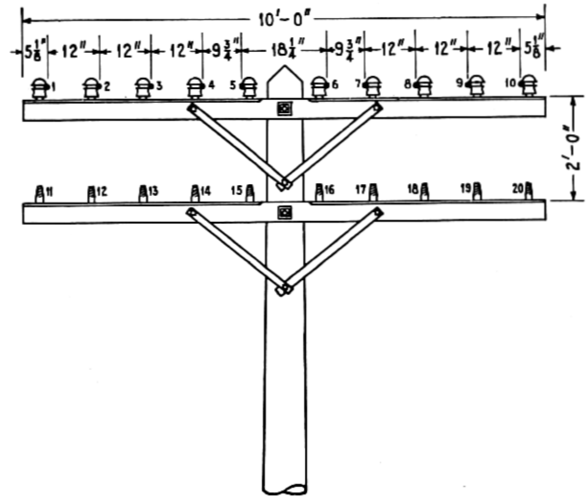

Figure 9—Showing arrangement of wires on telephone pole line

There are three gauges of wire in common use in the telephone plant, having diameters of 104, 128 and 165 mils,* respectively. The largest gauge, 165-mil pairs naturally afford the lowest attenuation and have been generally used in connection with the application of the longer systems. The pairs of this sized conductor are, however, now fairly well used up for carrier purposes and new installations are being made more often on the smaller diameter circuits.

Typical attenuation curves for the three gauges of wire and the extremes of weather conditions are given in Figure 10. It will be noted that the wet weather attenuation may be as much as 40 per cent higher than the dry weather attenuation. Also, these variations are greater at the higher frequencies.

It is interesting in this connection to consider the effect of the possible variation in a practical case. Take, for example, a 165-mil pair 200 miles long with a carrier channel frequency at 25 kilocycles. This means a total attenuation of 20 TU in dry weather and 29 TU in extremely wet weather, a variation of 9 TU or a current ratio of about 3 to 1. In the case of a still longer line these possible variations present rather startling figures. For example, in a 1,000-mile circuit the variation would be five times the above or 45 TU, which would

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* The term "mil" as here used is equivalent to 0.001 inch.

mean that if the circuit were set up to have a proper volume of transmission in dry weather and rain occurred over the whole line it would cause the speech at the receiving end to drop to but 1/180 of the desired volume if the proper readjustments of gain at the repeaters and terminals were not made. Fortunately, these line variations occur gradually, at least in the case of the longer lines.

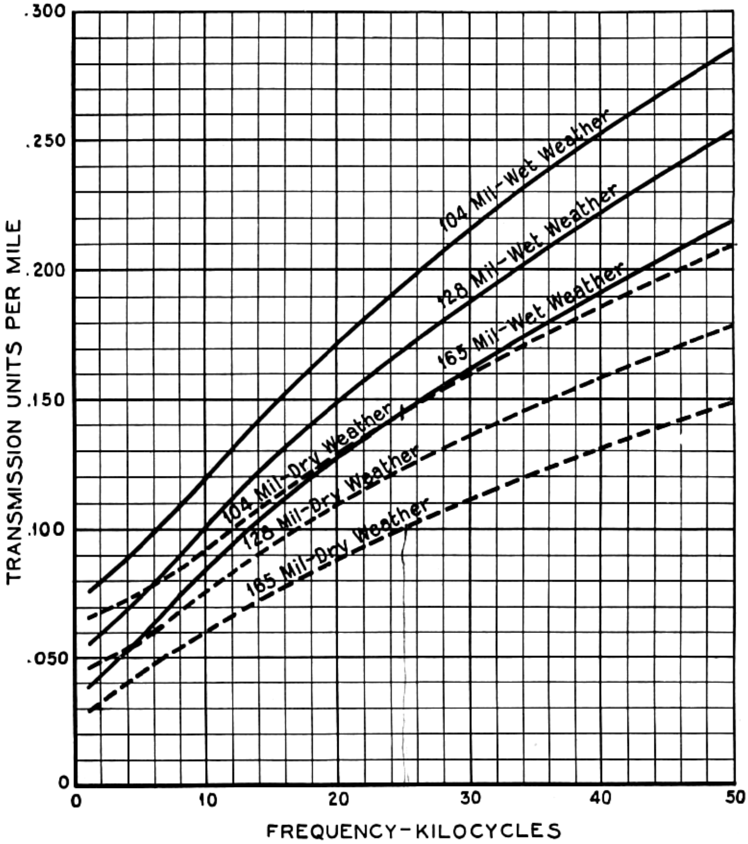

Figure 10—Attenuation curves for open-wire lines of different gauges at high frequencies

In connection with most carrier installations measurements are made[4] of line characteristics prior to the installation of the apparatus.

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[4] Reference, "High-Frequency Measurements of Communication Lines," by H. A. Affel and J. T. O'Leary, *A. I. E. E. Transactions*, V. 44, 1927, pp. 504–513.

An interesting picture is presented in Figure 11 which shows the attenuation variations with time on a particular line (about 110 miles in length) during the period in which a storm arose to cause the attenuation to increase. Later, when the insulators dried, the corresponding drop in attenuation was that shown. From these variations it is quite obvious that means such as afforded by the pilot channel are needed to insure that the talking circuits provided by the carrier channels remain at substantially constant volume.

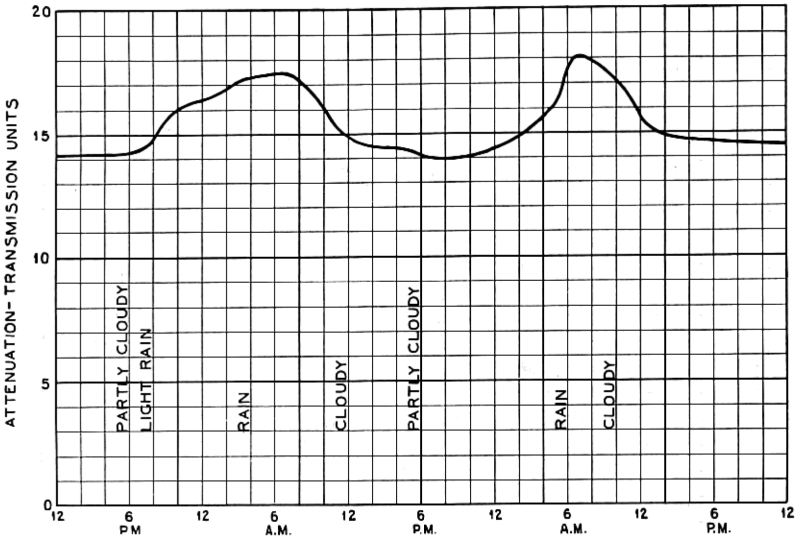

Figure 11—Variations in attenuation of a particular open-wire circuit

In addition to the improvement in stability effected by the use of pilot channel apparatus, substantial advances have been made in the design and application of special types of line insulators in which the high-frequency losses, particularly in wet weather, have been appreciably reduced, resulting in still further improvement in stability. The attenuation data given above are for the lines equipped with the older standard types of telephone insulators, which are still employed on the majority of circuits in the telephone plant. However, the newer types of improved insulators are now being applied and their use makes it possible to reduce the wet to dry weather attenuation variation by a factor of about 3 to 1 and to reduce the absolute value of attenuation at the higher frequencies by as much as 25 per cent. Further information describing the development work which has made possible these improved insulators will be made available at a later date.

While the circuits employed for the transmission of carrier telephone systems as noted above are largely of open-wire construction, where these circuits pass through the more populated districts of the country it is frequently necessary to insert sections of cable. The smaller closely spaced wires of cables make the problem of attenuation at high frequencies more serious, even where the cables are relatively short, say a mile or so in length. Typical attenuation curves of non-loaded cable pairs are shown in Figure 12.

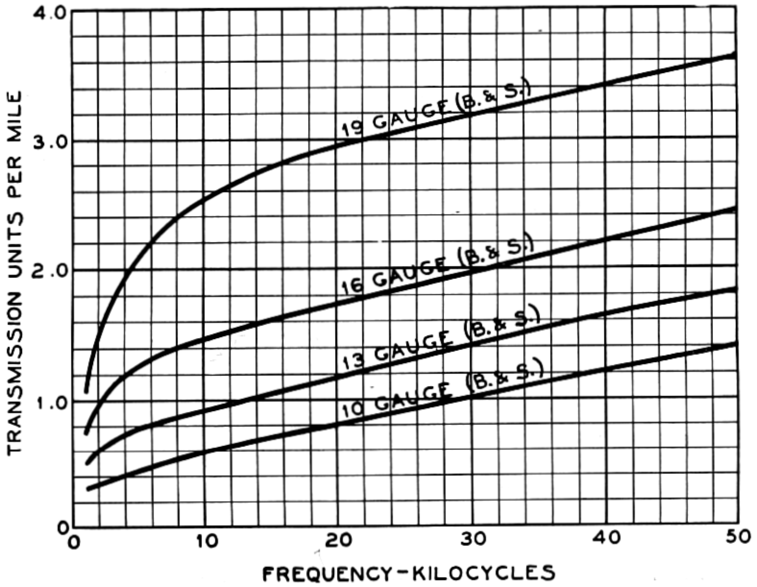

Figure 12—Attenuation of non-loaded cable circuits

This situation has led to the development of a special type of cable loading which permits making a substantial reduction in the attenuation for the higher frequencies and which also makes the characteristic impedance of the cable circuit more closely simulate that of the open-wire circuit so that the reflection effects discussed in detail later are thus greatly reduced. This is important, for, whereas the open-wire circuit characteristic impedance varies from 600 to 700 ohms, the non-loaded cable impedance is of the order of 130 to 150 ohms and the reflection losses and also certain resultant crosstalk effects as discussed later are, therefore, very substantial for even short lengths of non-loaded cable. The present standard types of carrier cable loading systems[5] provide for the use of loading coils spaced at intervals of approximately 930 feet. When loaded, the cable circuits have a characteristic impedance closely approximating the open-wire impedance over the frequency range used in carrier transmission. This same carrier loading also greatly improves the characteristics of the voice circuit. The high-frequency attenuation is reduced to approximately one half the non-loaded condition. A special type of cable loading is also available for use in improving the transmission characteristics of office cable and wiring and very short intermediate and entrance cable.

External Interference. The carrier channels are unusually free from noise due to extraneous induced currents. However, this is the result of attention to this factor in the design of the apparatus and in laying out the installations rather than anything inherent in the high-frequency feature as such. Our experience has indicated that it is possible, if care is not taken, to have interference from the following external sources:

a. Harmonics of power frequencies.
b. Irregular frequencies produced by abnormal power line actions, such as arcing insulators, charging lightning arresters of certain types, electric railways, series street lighting, etc.
c. Power line carrier systems.
d. Powerful transoceanic radio transmitters.
e. Lightning and other atmospheric disturbances.

In the matter of harmonics of the power line frequencies, the source of their generation normally limits them to very low magnitudes in the high-frequency range which has been employed for carrier systems on telephone lines. In this respect the carrier systems are, in general, affected to a lesser extent than the normal telephone circuits in the voice range. In the latter case, the power circuit harmonics frequently present serious interference problems because the harmonics in the power circuits are substantially greater at the lower frequencies.

Under particular conditions, however, such as, for example, in connection with a series street lighting system operated with individual series transformers or auto-transformers, where a burned-out lamp causes the saturation of the transformer magnetic circuit, induced harmonics of considerable magnitude, up to 30,000 cycles and over, have been measured in the carrier telephone circuits. Under the same

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[5] Thomas Shaw and Wm. Fondiller, "Development and Application of Loading for Telephone Circuits," *Bell System Tech. Jl.*, April 1926, pp. 221–281.

conditions, however, much larger harmonics are present in the voice-frequency range, so that the induction in the normal telephone circuit is much more severe than the carrier circuit.

A much more severe source of carrier interference has been found to result from the abnormal actions of power line circuits in which arcing phenomena occur. Interference of this sort has been noted and traced to such sources as arcing insulators, tree leaks, pantograph and trolley collector sparking, charging lightning arresters, unusual commutator or slip ring sparking, switching, etc. In the early days of operation of carrier systems, interference of this type formed a not uncommon source of disturbance. The situation was remedied in some cases by cooperation with the power companies concerned. On the whole, this source of interference has been greatly reduced in the past few years.

On occasions the carrier telephone systems have been interfered with by power line carrier systems operating on near-by power lines. Considering the widespread use of power line carrier telephone systems and the fact that they normally involve a transmitting power many times that of the systems described in this paper, this would, no doubt, be a more common source of difficulty if it were not a fact that such power systems adjacent to the telephone systems are operated well above the frequency range of the telephone line carrier systems.

Energy picked up from the high-power transoceanic radio telegraph stations, transmitting at frequencies in the carrier range, is an occasional source of interference, particularly in the east where carrier systems are located relatively close to the radio stations. The open-wire telephone lines act as long-wave antennæ and intercept the radio energy. This, of course, enters initially on the longitudinal wire circuit to ground. Due to residual line unbalances, some energy is, however, unavoidably passed on to the metallic circuits on which the carrier systems are operated, and enters the speech channel in the form of a tone or note similar to a heterodyne signal at a radio telegraph receiver.

Lightning and general static disturbances form a substantial part of the background noise which is found on all carrier lines. Its general magnitude is ordinarily small, except under certain conditions such as the case of near-by storms.

Transmission Levels. In the design and laying out of type "C" installations, the transmission level of a system is ordinarily not permitted to fall below a certain figure, which under particular circumstances might be about − 25 TU, with respect to the transmitting terminal. A transmission level diagram will serve to explain this limitation.

Let it be assumed that it is desired to effect carrier transmission using a type C-N system between points A and B, 240 miles apart on 165-mil conductors. The highest frequency channel is normally considered, which in this case would be 26 kilocycles. The total attenuation of the line at this frequency, as determined from the line attenuation data already presented, would be 35 TU for wet weather conditions of operation. A level diagram would accordingly picture the situation as noted in Figure 13. At point A sufficient transmitting gain would be provided by the equipment to bring the sending level to + 20 TU. The line attenuation in connection with transmission over the 240-mile circuit at point B would bring the level to − 15 TU. In order to obtain an overall talking circuit of, say, 10 TU., it would be necessary to operate with a receiving gain of 5 TU. It will be noted that in this particular layout the minimum line level is well above the limit set above. In fact, computations would indicate that the line circuit might be extended to the total length of about 300 miles, before the level limits would be exceeded. On longer lines, however, involving may repeater sections, the level limits are raised because of the cumulative effect of noise entering the circuit from a greater number of sources.

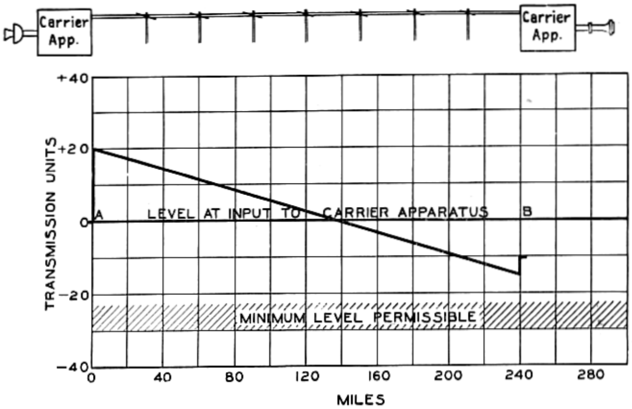

Figure 13—Transmission level diagram

The line circuit illustrated is of the simplest type and in a practical case involving sections of intermediate and terminal cable construction the attenuation would be considerably greater and the effective geographical distance covered for a particular type of apparatus would, **therefore, be less.**

Crosstalk. Telephone circuits which are simultaneously operating in close proximity on a pole line are normally subject to crosstalk because of the mutual inductance and capacity relations between the wires. The problem which this presents in a pole line structure carrying many circuits requires careful consideration, even where the frequencies are no higher than the voice range. The problem is cared for by the application of transposition systems, i.e., arrangements whereby the effect of these relations between the circuits tends to be canceled out by transposing the wires constituting the two sides of a circuit in an orderly fashion. These transposition systems are carefully designed and the transpositions to be applied in each circuit specified.[6]

When using still higher frequencies for carrier purposes, this problem is correspondingly increased as the mutual relations tend to become greater at higher frequencies. The phase changes as the currents progress along the lines are more rapid for the higher frequencies. The design of the transposition system capable of permitting the simultaneous operation of a number of carrier systems on the same pole line is a difficult problem. The subject is one of great complexity and to give it complete consideration would require more space than is available here. It may be noted, however, that, by means of special transposition layouts installed in the circuits being used for carrier transmission, successful operation is being obtained with a large number of carrier systems on the same pole line, both telephone and telegraph. The locations of transpositions in circuits used for carrier transmission occur more frequently than in circuits restricted to operation at voice frequencies, in some cases as frequently as every other pole.

Several factors in the apparatus design have contributed to lessen the hardship imposed by the crosstalk problem:

1. The standardization of arrangements whereby the same frequencies are only employed in a given direction on systems on the same pole line.
2. The equalization of the transmission levels between paralleling systems.
3. The use of "staggered" frequency allocations for systems in closest proximity.
4. A careful consideration of impedance relations in the line circuits and apparatus.

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[6] "The Design of Transpositions for Parallel Power and Telephone Circuits," H. S. Osborne, *A. I. E. E. Transactions*, V. 37, June 1918, pp. 897–936.

Frequency Directions. The importance of the use of a separate frequency for each direction of transmission may be considered by reference to Figure 14. If there are two paralleling telephone circuits employing frequencies (f_1) in the same range, and if there exists between the two circuits a certain amount of crosstalk, when there is a talker at the terminal of one system (No. 1) and a listener at the same terminal of the other system (No. 2), then the speech from the talker at the high level will enter directly into the sensitive receiving circuit of the listener. This is commonly called "near-end" crosstalk. In the case of a carrier circuit, the transmitting terminal would involve a certain amount of amplification. The receiving circuit would likewise, so that the net effect would be that the crosstalk between the two circuits would be amplified by the combined amount of gain or amplification present in the sending and receiving circuits. In telephone parlance it would be stated that this is a situation in which substantial level differences exist between the two circuits.

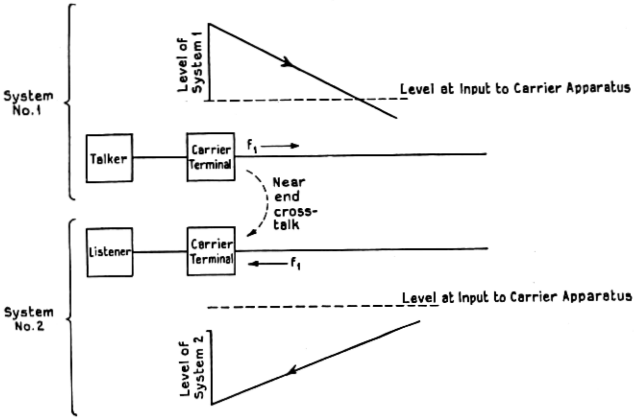


Figure 14—Diagram illustrating occurrence of near-end crosstalk between carrier systems employing the same frequency for opposite directions of transmission

On the other hand, in the case of two adjacent carrier systems employing the same frequencies for the same direction of transmission, a crosstalk situation involving only "far-end" crosstalk would exist, as illustrated in Figure 15. This assumes that near-end crosstalk by reflection as discussed later has been eliminated. In this case the talker and the listener would be situated at opposite terminals of the paralleling circuits and the crosstalk, while being amplified like the near-end crosstalk by the total gain in the transmitting and receiving circuits, suffers the attenuation of the line circuit which more than offsets the amplification. This is, therefore, a very substantial factor in favor of the two-frequency method of operation.

At the carrier frequencies, it has been found impracticable to design transposition arrangements providing for systems where the same frequencies are transmitted in opposite directions. It has been found that, while the two-frequency operation may mean fewer two-way

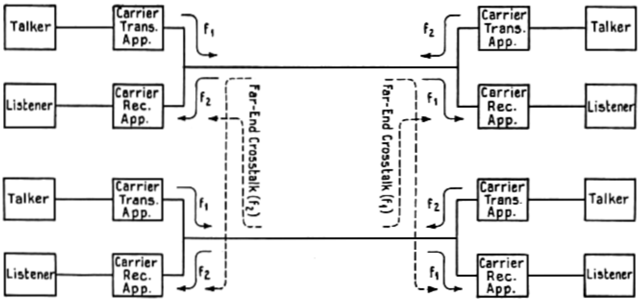


Figure 15—Diagram illustrating occurrence of far-end crosstalk only in carrier systems employing different frequencies for opposite directions of transmission

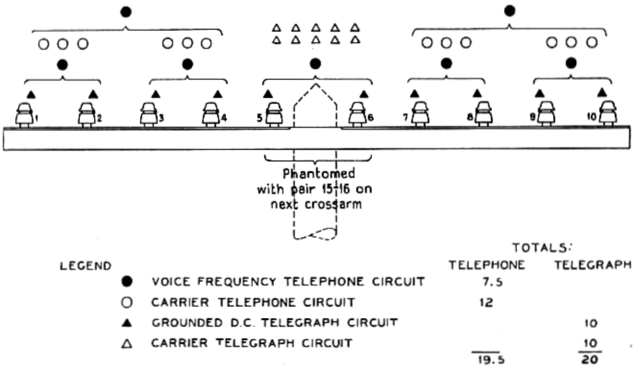
operating channels within the same frequency range on a single pair of wires than would be the case if the same frequency bands were provided for opposite directional transmission, the net result in the former case is to make it possible to obtain a greater number of channels on a pole line having many pairs of wires. The need for the directional coordination of frequencies has led to the general adoption of rules throughout the Bell System whereby the systems are all installed so that the low-frequency directional group of channels transmits east to west or north to south and the high-frequency directional group in the reverse direction, west to east or south to north.

Level Equalization. A situation involving an exaggeration of the crosstalk between two paralleling carrier systems may, of course, arise, even in the case of systems involving the transmission of the same frequency in the same direction for the two systems, if the transmission levels of the systems are not the same. If, for example, two systems operating between the same terminals are set up to have the same overall talking equivalent, and one system has a transmitting gain 10 TU higher than the other, the second system will have to have 10 TU greater receiving gain in order to provide the same overall equivalent. This would mean that this system would receive from the first system 10 TU higher crosstalk than if the levels of the two systems were alike. Efforts are, therefore, made in "lining up" the paralleling systems on a pole line so that as nearly as possible the same level relations are obtained for all systems, and the crosstalk tendencies are thus minimized.

Staggering of Frequency Bands. A substantial reduction of crosstalk is obtained through the staggering of an adjacent system frequency allocation as previously noted. Figure 5 shows the frequency allocations of the C-N and C-S systems. Because present standard types of telephone transmitters and receivers have response characteristics which exhibit the greatest sensitivity in the vicinity of 1,000 cycles, as the bands of two adjacent channels are shifted from an overlapping position, the crosstalk is appreciably reduced. In this case also the overlapping crosstalking points are always opposite sidebands and the intelligibility is completely lost even for the case of a substantial overlapping.

It is customary to install C-N and C-S systems on the two side circuits of a phantom group. The phantom group comprises four wires which are most closely associated electrically because they are employed not only to provide a telephone circuit on each pair of wires but a phantom telephone circuit each side of which is comprised of one pair of wires in parallel.

A typical arrangement of facilities afforded by one crossarm of the telephone line is illustrated by Figure 16. It will be noted that this



LEGEND		TOTALS: TELEPHONE	TELEGRAPH
●	VOICE FREQUENCY TELEPHONE CIRCUIT	7.5	
○	CARRIER TELEPHONE CIRCUIT	12	
▲	GROUNDED D.C. TELEGRAPH CIRCUIT		10
△	CARRIER TELEGRAPH CIRCUIT		10
		19.5	20

Figure 16—Arrangement of communication facilities on one crossarm

crossarm provides a total of twelve carrier telephone channels, five regular telephone circuits, two and one half phantom circuits, thus making a total of nineteen and one half telephone circuits. The telegraph facilities would total ten regular grounded d.-c. telegraph circuits, one for each wire, and ten carrier telegraph channels on the pole pair, thus affording a total of twenty duplex telegraph channels. This is, therefore, an average of approximately four telephone channels and four telegraph channels per pair of wires, which is obviously a fairly efficient use of the copper wire.

Impedance. It is found desirable in connection with communication circuits in general to match carefully the impedances of the various circuit and apparatus components if for no other reason than to insure the best transmission by keeping the reflection losses at a minimum. In connection with carrier systems the matter of crosstalk constitutes an additional important reason for doing this. As noted above, the crosstalk situation is simplified by the standardization of frequency arrangements by which only far-end crosstalk is normally received. This not only reduces the level differences at which crosstalk takes place as explained, but it simplifies the transposition design problem because near-end crosstalk is normally greater in magnitude than the far-end crosstalk. However, if the line circuit is irregular, i.e., if there are abrupt impedance differences in the circuit as it passes from point to point which bring about wave reflections, these may result in near-end crosstalk being reflected and appearing as far-end crosstalk, thus adding to the true far-end crosstalk and making it more difficult to keep within desirable limits. For this reason every effort is made in the layout of the carrier lines to avoid such reflection effects. This makes it desirable to load even relatively short cables including office cables and wiring. The apparatus terminal impedances are also carefully designed, so that their values simulate the characteristic impedance of the line circuits over which the systems are operated.

Overall Line Circuit. A situation sometimes occurs in a long carrier system where the line is made up of sections in which the wire pairs occupy different pin positions in each section and the voice circuit on the pair in which the carrier system operates is terminated at different points or perhaps joins other lines. The use of line filter sets at the intermediate points makes this arrangement possible. Special transfer line filter sets have also been designed where it is desired to transfer the carrier currents from one pair of wires to another without affecting

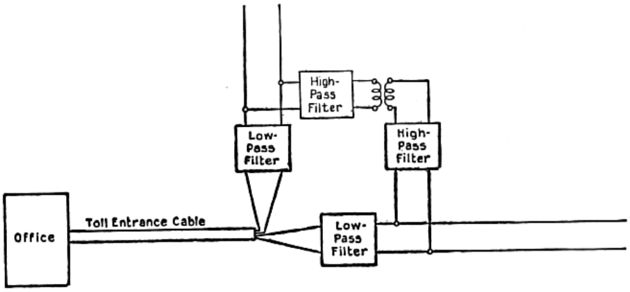


Figure 17—Schematic of high-pass transfer line filter circuit

the destination of the voice circuits and with a minimum impedance irregularity for either circuit. These line filters are sometimes mounted on poles, so that this transfer may take place where lines join at an outside point and where office equipment cannot be installed. A circuit arrangement illustrating the use of the pole-mounted high-pass transfer filter set is shown in Figure 17.

EQUIPMENT PROBLEMS AND TYPICAL INSTALLATIONS

The increasing use of carrier telephony as a substitute for line construction in providing toll facilities on long circuits has, like the development of toll cables, resulted in further increasing the proportion of the plant investment represented by the equipment within the offices. It has likewise required that a greater part of the maintenance effort involved in taking care of a given number of facilities be devoted to the equipment. These factors have made the design and arrangement of the carrier equipment matters of considerable importance. Recent developments in these respects have, therefore, been directed toward obtaining a high degree of adaptability of the carrier equipment to practical use in the telephone plant. Economies in design have also resulted which have been an important factor in extending the usefulness of the equipment.

The type "C" carrier telephone equipment is mounted on panels employing a uniform dimensional system in a manner similar to the other recent telephone developments. Arrangements have been devised so that in the future this mounting method will permit the desired close association between the carrier filters and other related apparatus in the lines in order to minimize high-frequency losses and impedance unbalances within the offices. Signaling arrangements flexibly adapted to present plant conditions have been provided.

The high frequencies and power levels used in carrier telephony and the frequency conversion functions of the system are the principal electrical factors which affect the arrangement and amount of equipment involved. The high frequencies necessitate careful wiring, shielding, and location of certain units with respect to others to avoid undesirable inductive and impedance effects. The modulation and demodulation processes and the high energy levels required necessitate the use of numerous vacuum tubes, with the consequent need of suitable sources of power.

Typical System Equipments. As noted previously, a long carrier telephone system involves equipment at a number of intermediate repeater stations in addition to that at the terminals. Figure 18

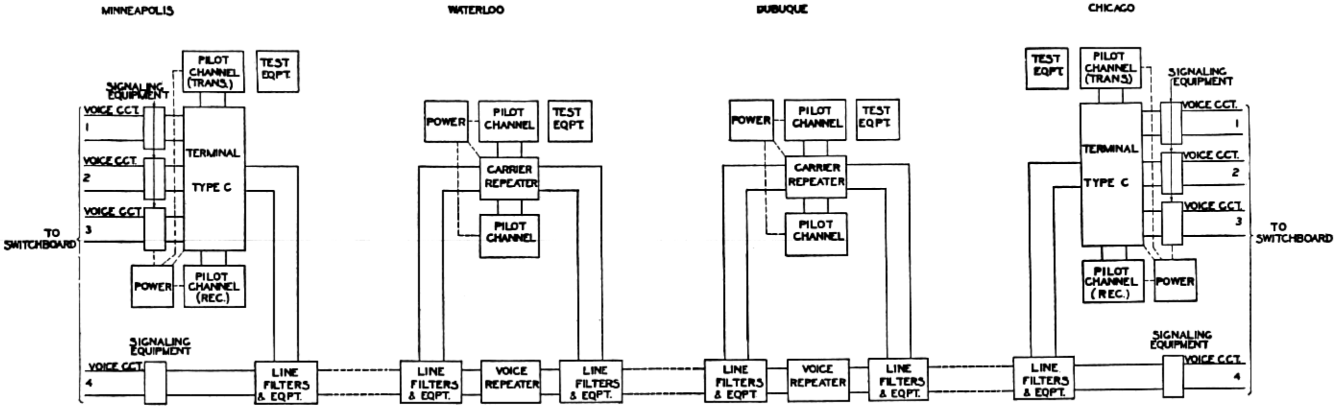


Figure 18—Elementary diagram showing principal equipment groups in typical type "C" carrier telephone system

shows the principal equipment groups involved in a typical long carrier system. The particular system illustrated is one of those between Minneapolis and Chicago, with repeater stations at Waterloo and Dubuque, Iowa. The carrier repeater equipment is ordinarily additional to voice-frequency repeater apparatus used in the wire line as mentioned above and is connected so that the high-frequency currents for the carrier pass around the voice-frequency repeater. The wires concerned are employed also for d.-c. telegraphy by the use of composite sets.

The principal groups of equipment involved in such a system include the carrier sending and receiving equipment and filters at the terminals, the repeater amplifiers and filters at the intermediate stations, and the line equipment and pilot channel equipment at all points. In addition, power supply equipment and testing equipment are required at all points, and voice-frequency and signaling apparatus at the terminals.

The total amount of equipment involved in a typical carrier telephone system shown in Figure 15, exclusive of the power supply, includes altogether about 188 panels assembled on racks equivalent to 14 bays [7] and occupying a total floor space, including aisle space, of about 84 square feet. If the three channels which the system ordinarily provides were obtained by regular wire circuits, the office equipment might amount altogether to about 36 panels and 1.7 bays, occupying about 10 square feet. Thus, in a typical case, about eight times as much office equipment, other than that for the power supply, might be required to furnish a given number of facilities by carrier telephony, in comparison with that needed for the equivalent number of ordinary wire circuits.

Terminal Station Installations. The principal equipment groups comprising a terminal of a type "C" system are indicated in Figure 19. A typical assembly showing a majority of these equipment groups is given in Figure 20. This does not include the signaling equipment, the pilot channel, or the power equipment. A rear view of this same assembly is shown in Figure 21.

Returning to Figure 20, the right-hand bay contains the apparatus comprising two channel terminals. The middle bay includes the third channel apparatus and the terminal transmitting and receiving amplifiers and directional filters which are mounted in the upper portion. The box-like units on both bays are the band filters and directional filters. On the right-hand bay the upper of the panels

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[7] A bay consists of two channel or I beam uprights, ordinarily about $11\frac{1}{2}$ feet high, and spaced so as to mount unit panels 19 inches wide and of varying height.

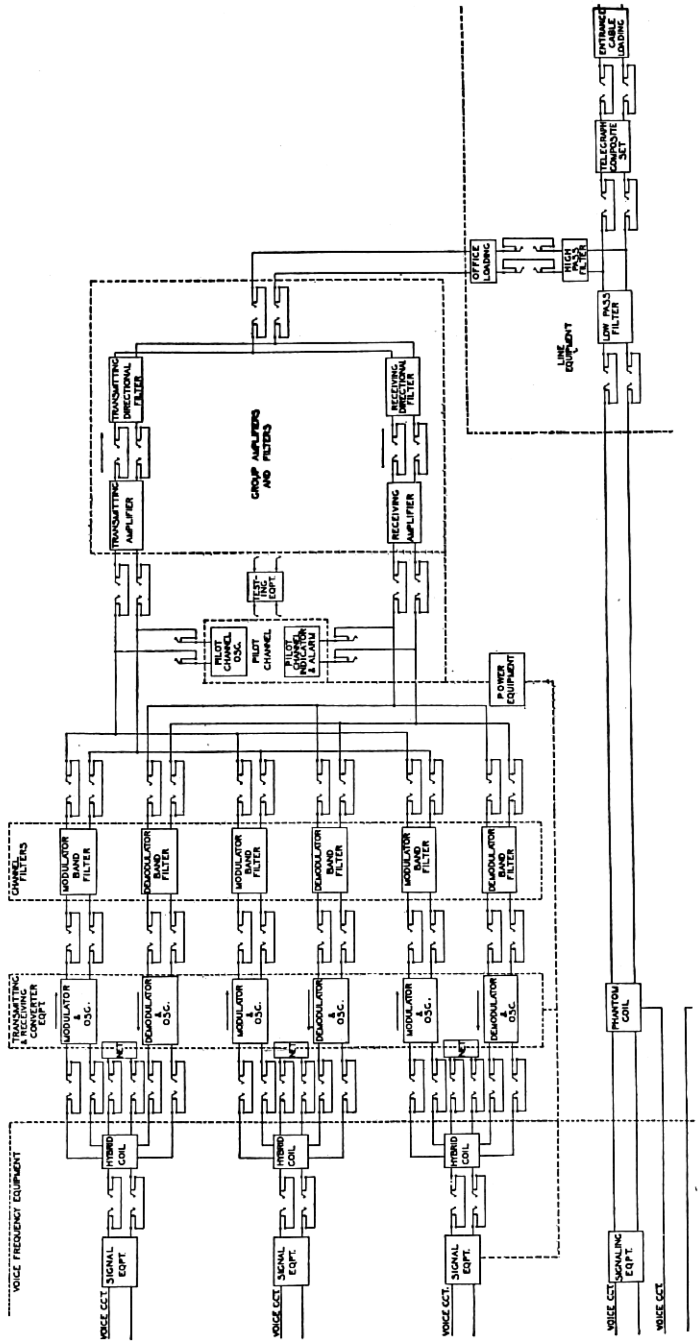


Figure 19—Schematic showing principal units comprising type "C" terminal equipment

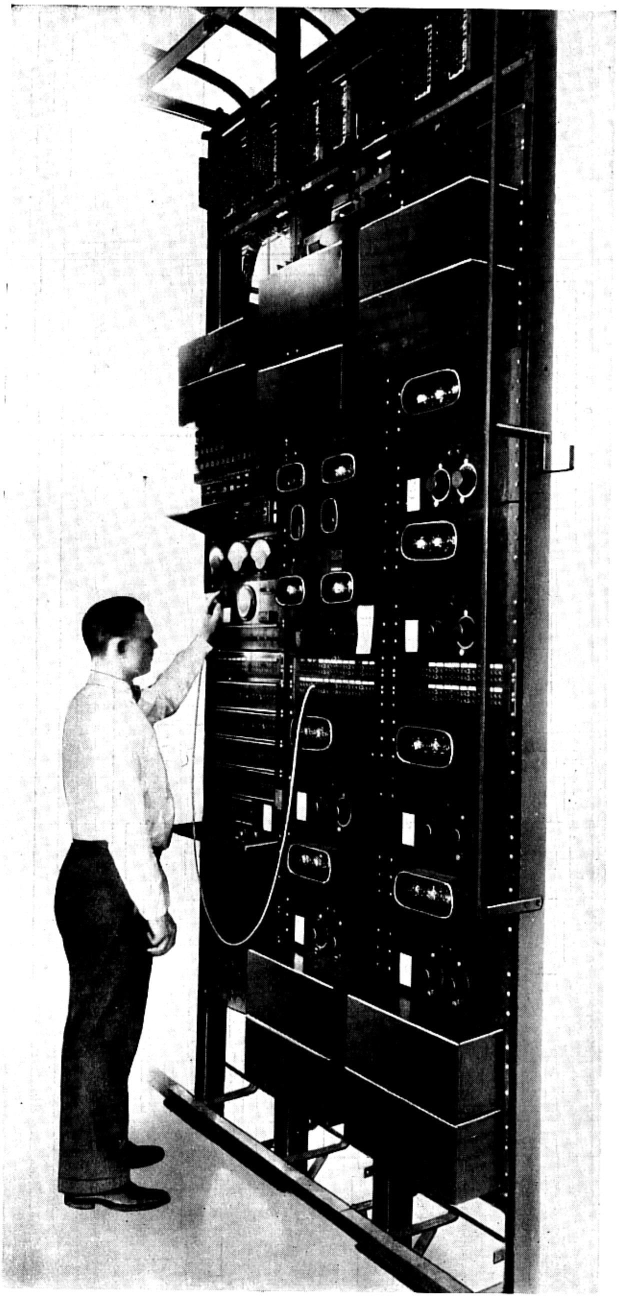


Figure 20—Type "C" carrier telephone terminal equipment, typical assembly of system. (Front)

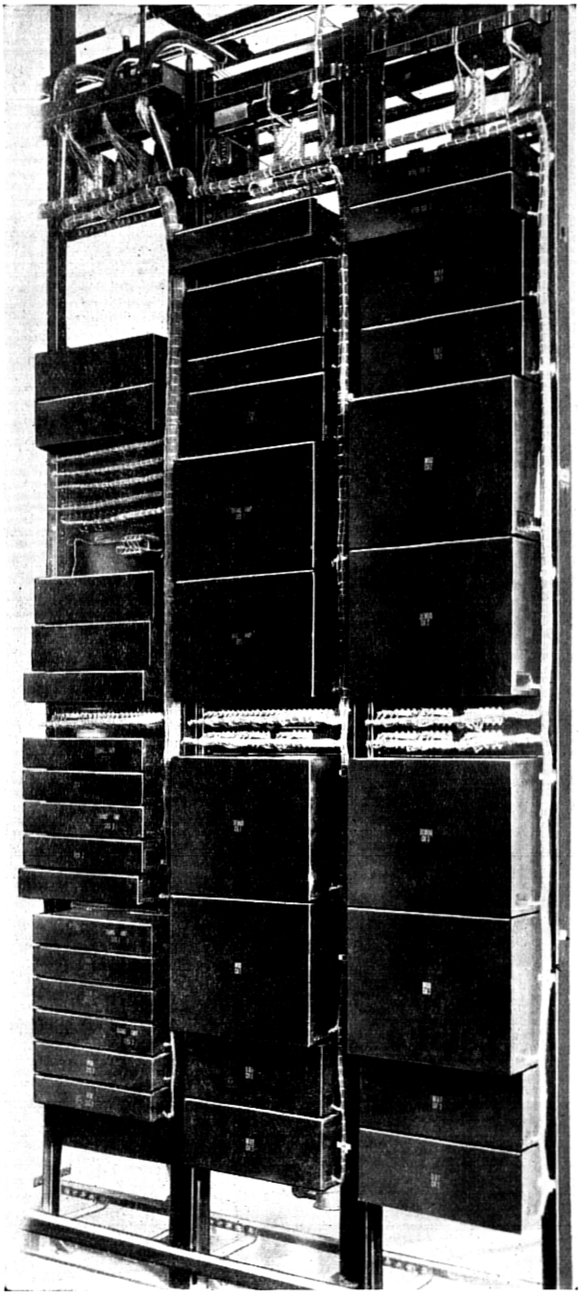


Figure 21—Type "C" carrier telephone terminal equipment, typical assembly of system. (Rear view)

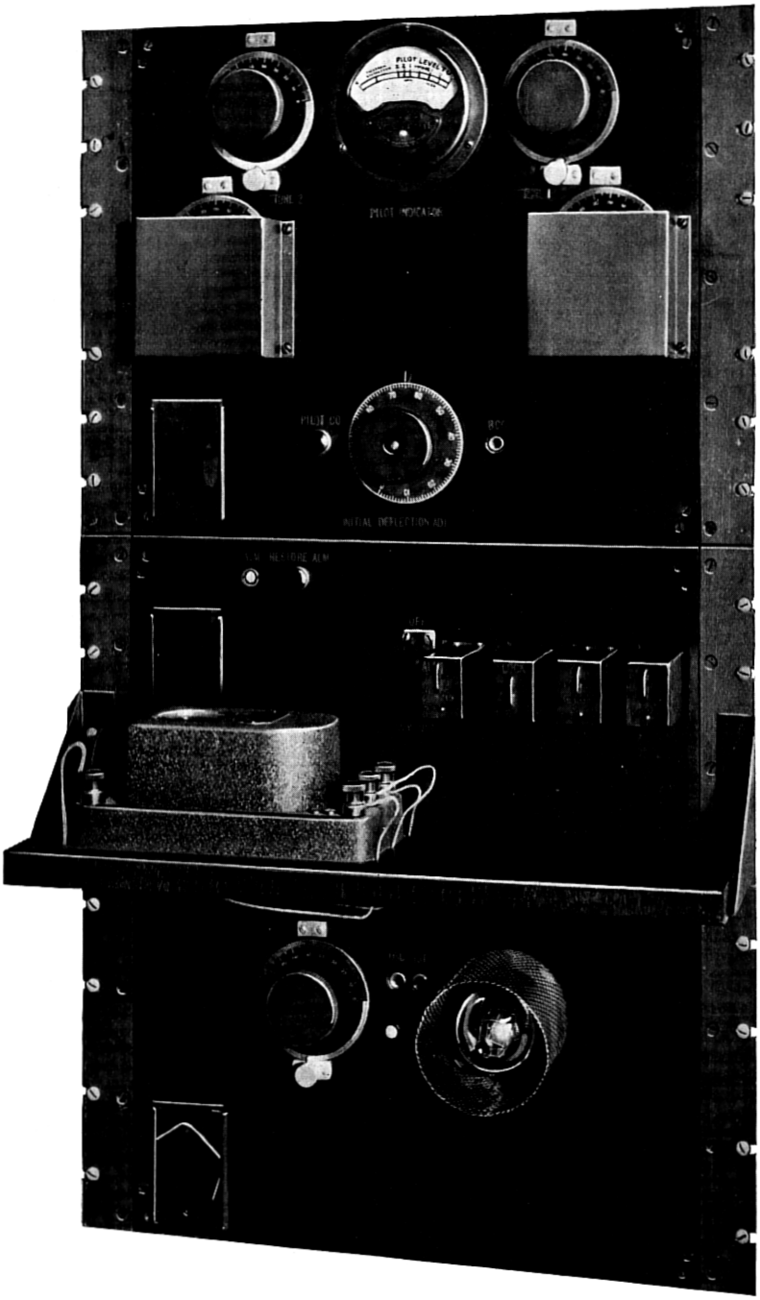


Figure 22—Typical assembly of pilot channel equipment in terminal installation

with three vacuum tubes is the modulator-oscillator panel of one channel. Below it is the demodulator-oscillator panel of the same channel. Below the latter and in the center of the bay is the jack mounting strip which makes it possible to disconnect, or switch for testing purposes, the various units of the complete equipment. The demodulator-oscillator panel and modulator-oscillator panel, respectively, are the next two panels of the second channel. The terminal strips will be seen at the top of the bays. The metal shields surrounding the vacuum tubes are useful for mechanical protection only. The testing and power distribution equipment is located in the left-hand bay.

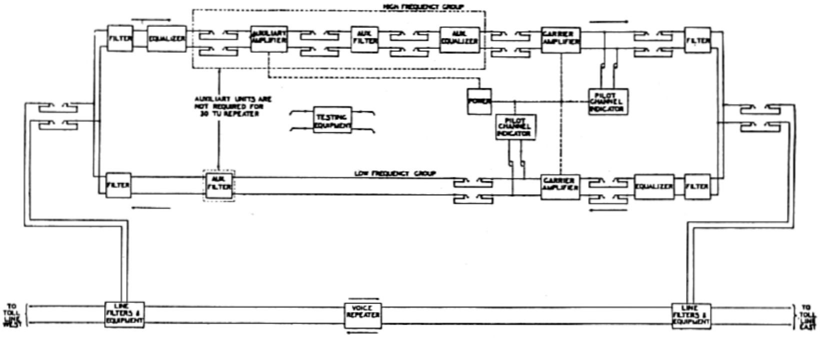


Figure 23—Schematic showing principal equipment units in carrier repeater circuit

The pilot channel apparatus at the terminal station, which is employed in regulating the performance of the system to compensate for variations in the line equivalents, is assembled in a typical installation as shown in Figure 22. This apparatus may be located adjacent to the carrier terminal apparatus. The upper panel is the indicator unit with the indicator meter shown in the upper center of the panel. The panel immediately below this is the alarm panel with its voltmeter relay. On both of these panels the associated vacuum tubes are mounted in the rear. The lowest panel is the oscillator panel with its vacuum tube and frequency control.

Typical Repeater Station Installations. The equipment at each carrier repeater station consists mainly of the units indicated in Figure 23. It is seen from this figure that the principal items are the line filter equipment, the amplifiers, the equalizers, the directional filters, and the jacks provided for testing and patching the equipment. Pilot channel equipment, power supply equipment, and testing equipment are also included. The amplifier equipment in each carrier repeater,

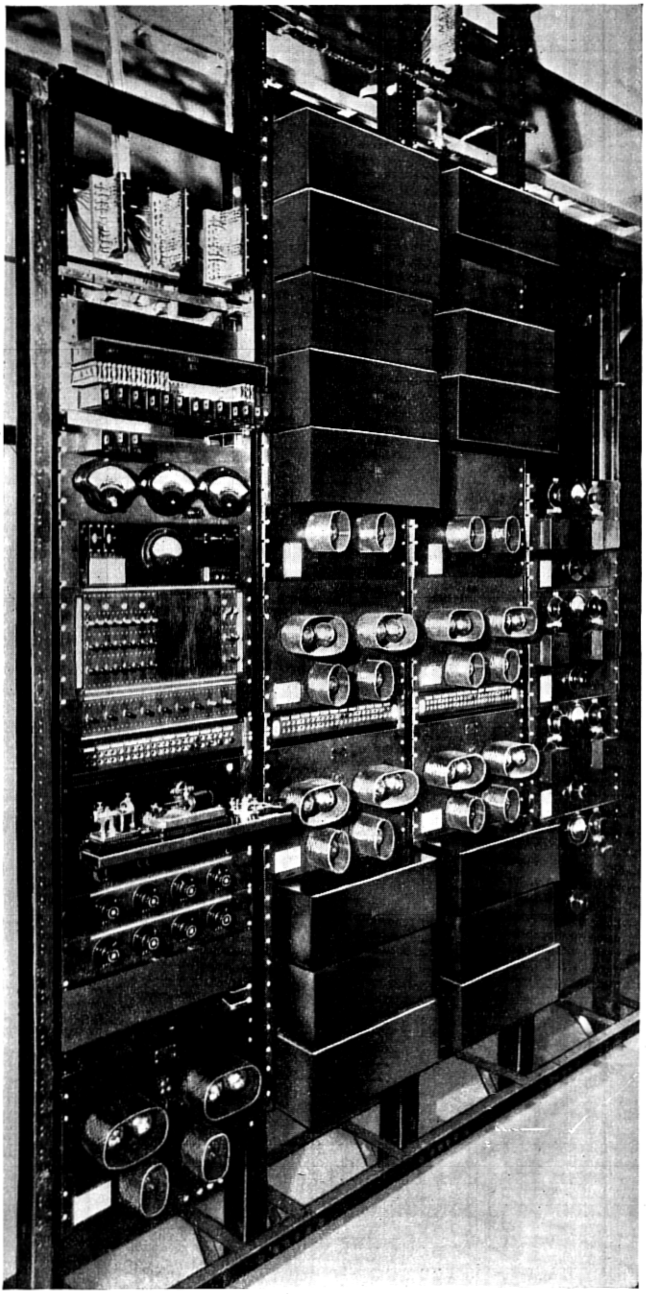


Figure 24—Typical installation of carrier telephone repeater equipment. (Front view.)

other than the 15 TU auxiliary amplifier, is identical to the group amplifiers employed in each terminal station. The filters are also identical in type, excepting that twice as many directional filters are required at each repeater station as at each terminal.

A typical complete installation of two carrier repeaters with testing and battery supply circuits located in the bay at the left is shown in Figure 24. The bottom panel on the left-hand bay is a reserve amplifier. Above this panel are the filament rheostats, telegraph instruments, jack panels, key panels for controlling the power supply, a panel containing a thermocouple and meter for testing, meters for reading currents and voltages, and finally the alarm relays. These last are operated by failure in the plate current in the amplifier tubes, thereby indicating when a tube burns out, or failure of either A or B battery supply.

Each repeater bay in this case, Figure 24, contains an auxiliary amplifier to increase the gain in the high-frequency group. From

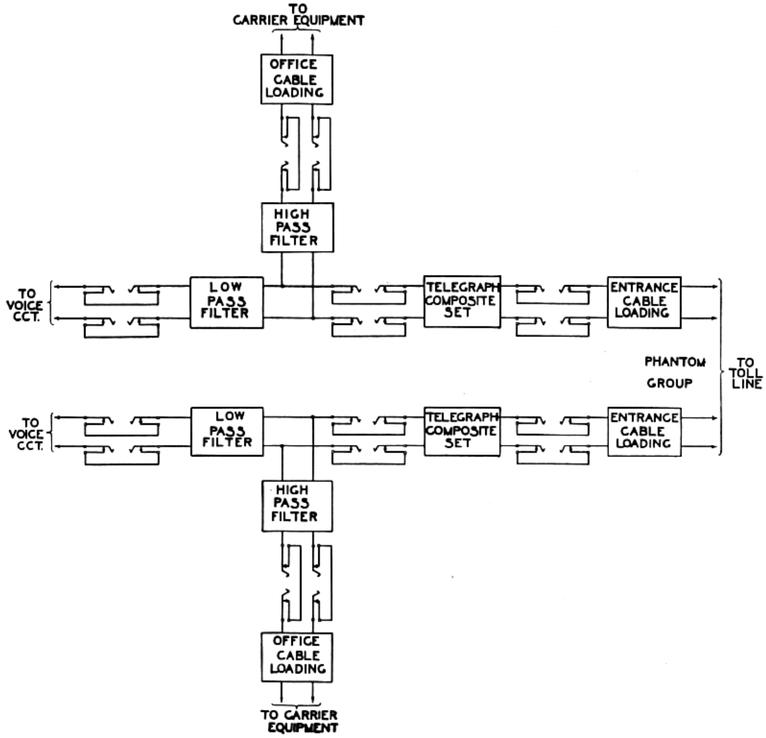


Figure 25—Schematic circuit showing line filter equipment for type "C" carrier telephone terminal. (Phantom group)

top to bottom the panels are input filters, auxiliary filters, equalizers, auxiliary amplifier, two regular amplifiers separated by a jack panel, and output filters. The arrangement of filters and equalizers is chosen to minimize any tendency toward inductive feed-back effects between the output and input circuits of any one repeater as well as crosstalk between different repeaters on adjacent bays.

The pilot channel equipment at a carrier repeater station is similar to that employed at the terminal stations, excepting that the alarm and oscillator panels are not included. The alarm apparatus is omitted in this case, since it is not the practice to have the carrier repeater attendants readjust the carrier repeaters to take account of line changes, excepting when instructed to do so by the attendants at the terminal stations where the alarm apparatus is installed. The pilot channel equipment at each repeater station thus consists principally of an indicator panel associated with the transmission circuit in each direction, which is assembled with the other equipment as previously shown at the extreme right in Figure 24.

Line Equipment. Figure 25 shows the principal line equipment units which are closely associated in effecting connection between the high-frequency circuit of the carrier system and the voice-frequency line. This equipment, consisting of the line filters, composite sets, and entrance and office load coils, is mounted together in one assembly and located as near as practicable to the other carrier equipment. A method of assembly which is now under development is shown in Figure 26. The bay shown contains the line equipment for two phantom groups.

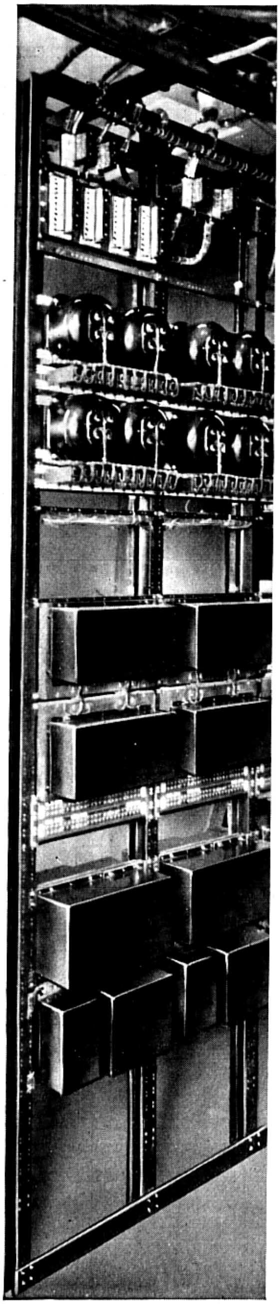


Figure 26—Arrangement of line equipment in one assembly for type "C" carrier telephone. (Front view)

This compact method of assembling and wiring the line equipment reduces the amount of office cabling required for the carrier and, therefore, reduces the possibility of inter-system crosstalk between carrier systems within the same office. The crosstalk requirements in an office may be more severe than on the pole lines because the level difference between circuits which operate on different pole lines terminating at the same office may be as much as 50 TU. As an aid in obtaining the required electrical separation all high-frequency wiring is reduced to a minimum by segregating and mounting together all line equipment associated with a single circuit. No high-frequency circuits appear at the toll testboard. The toll lines may be tested from the testboard by means of trunks between the testboard and the line equipment bays. All the carrier equipment is thoroughly shielded in such a manner that the separation between the equipment of any two systems is 120 to 135 TU.

The carrier line equipment at a carrier repeater station is generally similar to that at the terminal stations, as previously shown in Figure 26. At each repeater station, however, this equipment is provided in the lines in both directions. Two types of low-pass line filters are employed at the repeater station, one adapted to circuits in which both carrier and voice-frequency repeaters are used and the other, which is less commonly used, for circuits employing only carrier repeaters and where the voice circuit continues through without a repeater.

Voice-Frequency and Signaling Equipment. The general function of the voice-frequency terminating equipment is to associate, by means of a hybrid coil and network, the ordinary two-wire circuits in the telephone switchboard, including both talking and signaling functions, with the sending and receiving branches of each of the different

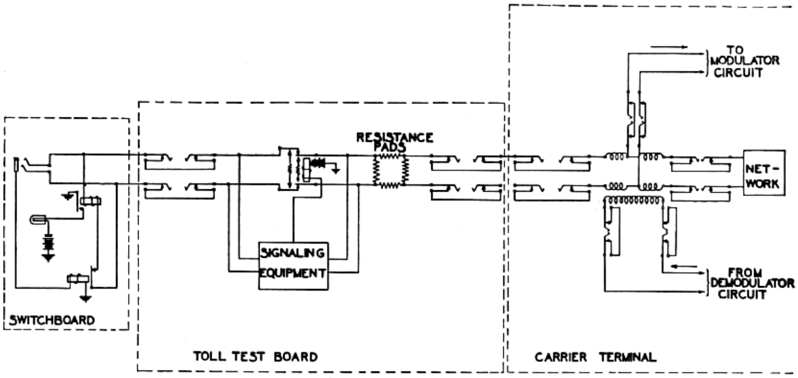


Figure 27—Schematic of voice-frequency circuit for type "C" carrier telephone system

carrier channels. The general arrangement of this equipment in the circuit is shown in further detail in Figure 27. This includes the signaling equipment and makes provision for the connection of a balancing network.

The use of a two-wire termination for the carrier system is necessary because ordinary telephone circuits at the switchboards, such as trunks, subscribers' lines, etc., are of the two-wire type and the cord circuits for interconnecting these are of this type. Hence, such a termination of the carrier system makes it possible to connect it to other circuits with the same apparatus and in the same manner as with ordinary telephone circuits.

The signaling apparatus consists of a 1,000-cycle ringer of the type which is employed on long voice-frequency lines. This is connected to the voice-frequency terminal of the carrier system in the same manner as to other voice circuits. The use of 1,000-cycle signaling with the carrier has been desirable in place of the more simple low-frequency signaling apparatus used on shorter lines, since frequencies less than 200 cycles are not efficiently transmitted.

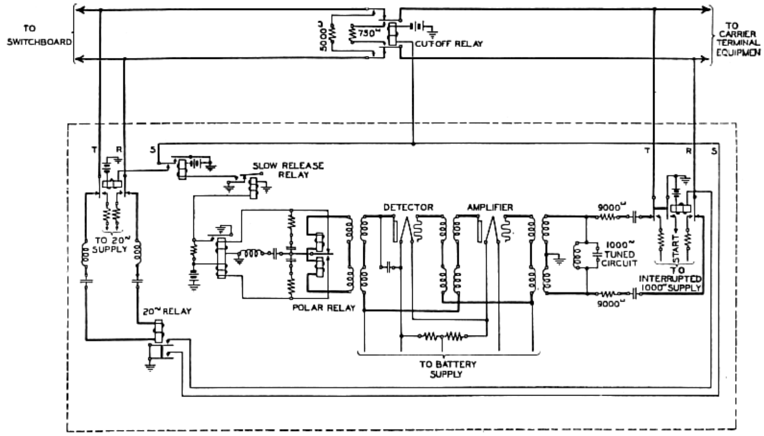
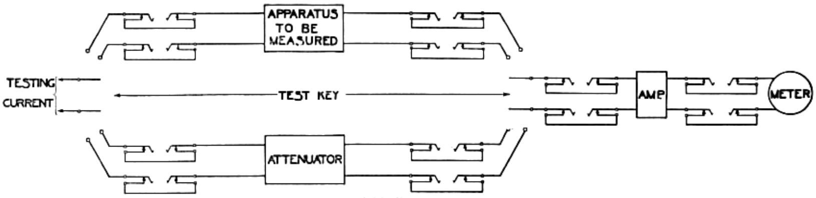


Figure 28—Schematic of 1,000-cycle ringing circuit

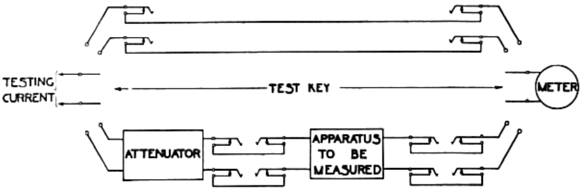
Figure 28 shows a simplified diagram of this type of ringer. The transmitted signaling currents as impressed upon the carrier channel are of 1,000-cycle frequency interrupted at a speed of 20 interruptions per second. This ringing current supply is obtained either from 1,000-cycle generators or vacuum tube oscillators. Such currents, while in the voice-frequency range and thus capable of being transmitted readily, form a signal of sufficiently distinctive character to permit separation from ordinary voice currents. Thus, practical freedom from voice interference with the receiving apparatus is obtained, since this apparatus is designed to respond to very small currents of this character but to discriminate sharply against other currents.

Tests and Adjustments of Apparatus. For the purpose of testing and "patching" (i.e., interconnecting various equipment units in the carrier system), jacks are provided as previously shown in Figure 19. The equipment which is employed for testing and adjusting the carrier apparatus provides means for measuring gains and losses at the various frequencies encountered and includes a supply of testing current at these frequencies. The general arrangement of the testing apparatus provided for measuring gains and losses is shown in Figure 29. This is assembled with the other carrier equipment as previously shown in Figure 20. It consists chiefly of means for switching a known loss in the testing circuit, an attenuator, and a calibrated thermocouple type measuring instrument for determining the value of the current transmitted through this apparatus. The 1,000-cycle current is used for practically all testing of the terminal apparatus.

The testing equipment at a carrier repeater station is arranged in a manner similar to that at the terminal stations, as previously shown in a general way in Figure 29. It requires in addition, however, a carrier-frequency oscillator. Only high-frequency currents are transmitted through the carrier repeater, hence the 1,000-cycle supply employed at the terminals where modulation and demodulation of these carrier currents occur, is not useful in testing the repeater equipment.



TESTING CIRCUIT FOR MEASURING LOSSES



TESTING CIRCUIT FOR MEASURING GAINS

Figure 29—Schematic of testing circuit for type "C" carrier telephone system

It is customary to make periodic tests of the equipment. On the longer circuits [8] each day the channels are "lined up" for the required overall transmission equivalents. At less frequent intervals the vacuum tubes are checked for emission, the gains of the sending and receiving branches are measured, the carrier synchronism is checked, etc.

Vacuum Tubes. Two principal types of vacuum tubes are employed in this system. One of these is the so-called "L" tube. This tube has a filament circuit requiring a current of approximately 0.5 ampere with a voltage drop of 4.0. It has a μ of 6.5, and a normal plate current, when used as an amplifier with a "B" voltage of 130 and a "C" biasing potential of 8, of about 6.5 milliamperes.

For the output stage of the amplifier a higher capacity tube is employed. This is a so-called "O" tube having a μ of about 2.5, a filament current requirement of approximately one ampere at a voltage drop of 4.5. The normal plate current when used as an amplifier with a grid biasing potential of 22 and a plate potential of 130 volts is from 17 to 35 milliamperes.

In addition to the above the pilot channel uses a low-filament current tube. This tube has a μ of 8, a filament current of .060 ampere, and a filament voltage drop of 3 volts. The normal plate current when used as an amplifier with a grid biasing potential of 7 volts and a plate potential of 130 volts is approximately .003 ampere.

The tubes employ oxide-coated filaments and have been designed to be especially long lived to meet daily 24-hour service requirements.

Power Supply. The power required for the carrier equipment is taken from the telephone office supply where this is adequate. Usually the 24-volt central office power plant is suitable for the purpose, and the 130-volt supply for the plate circuits of the tubes is taken from the same batteries provided for telephone repeaters if available. The carrier requirements, however, may amount to a substantial addition to the load on the power plant, particularly where several carrier systems are installed in a relatively small office.

The amount of power required for a typical carrier telephone system is substantially larger than the usual telephone power requirements for the same number of facilities. Each system terminal requires approximately 8 amperes at 24 volts and about 400 milliamperes at 130 volts. The power required for each carrier repeater amounts to about 4 amperes at 24 volts and 250 milliamperes at 130 volts. Thus, the total power required for one three-channel

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[8] W. H. Harden, "Practices in Telephone Transmission Maintenance Work," *Bell System Tech. Jl.*, V. 4, Jan. 1925, pp. 26–51.

system with two intermediate repeater stations would be in the neighborhood of 24 amperes at 24 volts and 1.3 amperes at 130 volts, amounting altogether to about 750 watts. This corresponds roughly to the amount of power consumed by about 80 telephone repeaters, so that the total power required for three such carrier systems would be about equal to that required for a cable repeater station having between 200 and 300 repeaters. Assuming 2 or 3 repeaters in a typical voice circuit, the carrier systems are seen to require over ten times as much power as voice circuits in providing the same facilities.

The best results are obtained with the carrier systems when very close regulation of this power supply is maintained. About ± 1 volt for the 24-volt supply and ± 5 volts for the 130-volt supply are desirable limits of variation. Means for obtaining such regulation are added as required to the existing power plant. In the larger offices this may consist of a duplicate battery with full-floating operation. In the smaller installations, a relay regulating circuit may be added which controls the filament current as the voltage varies from 20 to 28 volts. This consists of a sensitive voltmeter relay arranged with accessory relays to cut resistance in and out of the individual filament supply circuits as the voltage varies.

Design of Carrier Apparatus

Many will, no doubt, be interested in the further technical details of some of the more important units of the carrier system.

In the development of the apparatus considerable preliminary work was necessary to determine the circuit requirements imposed upon the individual units. For example, preliminary to the design of the filters, laboratory studies were made to find what interfering frequencies might be expected in a channel and what attenuation the different filters must offer at various points in the frequency range, in order that the system should provide speech of satisfactory quality and freedom from interference. As a result of such work, it was possible to make the requirements of the filters no more stringent than absolutely necessary, thus keeping the cost down to a minimum while insuring adequate performance. Preliminary studies were also made on the other parts of the system such as modulator, demodulator, oscillator, etc. In the descriptions which follow, no attempt has been made to describe this preliminary work, the discussion being limited to the requirements imposed, and the circuits devised to meet these requirements.

Modulator and Transmitting Oscillator. A circuit drawing of the modulator is shown in Figure 30. It may be considered that the function of the modulator is to translate the voice frequencies along a frequency scale to some assigned location in the band of frequencies to be occupied by the carrier system. The carrier frequency controls the location of the shifted voice band or sideband, and the oscillator, which provides this frequency, is made an integral part of the modulator unit. The modulating process requires a circuit element having a non-linear response characteristic to produce the sideband from a combination of the carrier and voice frequencies. In this circuit the three-element vacuum tube is operated to give this required characteristic.

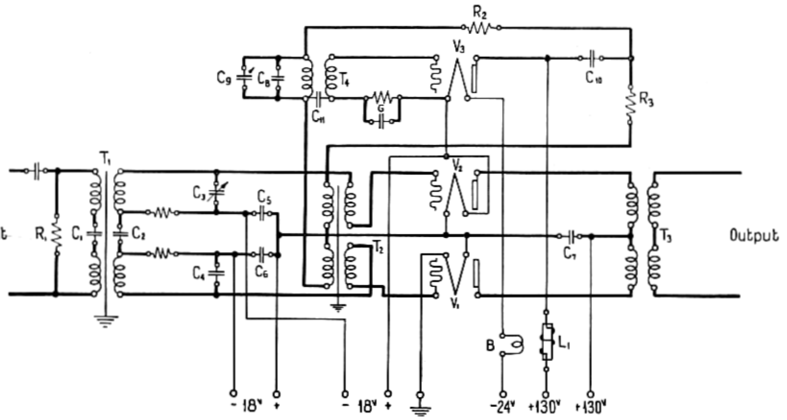

Figure 30—Schematic of modulator circuit and transmitting oscillator

Since the carrier is not transmitted in the type "C" system, each modulator and demodulator becomes a complete and independent frequency changing unit. As previously noted, the frequency stability of each oscillator must be sufficiently good so that the carriers of the corresponding modulator and demodulator units will differ but slightly in frequency so as not to affect unfavorably the speech which is transmitted. In this connection both naturalness of the received speech and intelligibility must be considered. In the type "C" system satisfactory results have been obtained by holding the difference between the carrier frequencies of any two associated units due to all causes to within about 20 cycles.

The usual causes of frequency variation are fluctuations in the A and B battery supply and changes in temperature and humidity. Vacuum tubes have to be replaced periodically and differences in the tube characteristics may cause a slight variation in the frequency.

The type of oscillator circuit was chosen to furnish the greatest frequency stability with variations in power supply, particularly in the plate battery. Fluctuations in the filament current are reduced by the use of ballast resistors to a point where they do not appreciably affect the oscillator frequency.

In order to maintain stability with temperature and humidity changes, it was necessary to develop circuit elements (primarily the inductance in the oscillating circuit) which were not greatly affected by these variables. As a result the oscillators vary less than 10 cycles per second at the highest carrier frequency with power variations within the limits of plant maintenance, and have a frequency temperature coefficient of approximately .002 per cent per degree Fahrenheit. This corresponds to about one cycle per second per degree Fahrenheit in the highest frequency units used in the type "C" system. The temperature difference between offices containing terminal equipment seldom exceeds 20 degrees Fahrenheit.

An extreme change in frequency of 20 cycles per second may be encountered with different tubes. Maintenance experience has shown that it is usually unnecessary to check the synchronization of the modulator and demodulator carrier frequencies more often than once a week, unless tubes are replaced or some other unusual circuit change occurs.

The modulating tubes are placed in a push-pull arrangement, and the carrier voltage is applied to both grids in phase and the suppression of the carrier frequency secured by a differential connection of the output transformer windings. It is difficult to completely suppress the carrier and a limit is set upon the amount which can be allowed on the high-frequency line without causing interference between systems. This limit requires that the carrier flowing out from the modulator should not exceed approximately 500 microamperes. With varying conditions of power, the balance of the modulator cannot be maintained absolutely constant, so that to insure meeting this requirement under the worst conditions it is necessary to adjust the balance under normal conditions to a point where the carrier has been reduced to about 150 microamperes at the output of the modulator. The side-band current flowing at this place in the circuit is ordinarily of the order of 2,000 microamperes. Adjustment of the carrier balance is made by changing the condenser across one half of the input circuit and by selecting tubes.

A further requirement imposed on the modulator unit is that of gain stability. In order to maintain sufficiently constant transmission over a circuit there must be a high degree of inherent stability in all those units whose variations are not included in the indications of the pilot channel. The modulator and demodulator are the only units in this category.

In the modulator and demodulator the principal factors tending to cause instability of gain are the variations in plate and filament battery where these occur and changes in the tubes during their life. A characteristic behavior of the modulator described below has been used to advantage in minimizing this instability. The gain of the modulator for varying values of the carrier voltage passes through a maximum near the point where the grids of the modulator tubes are driven to a positive potential, with respect to the filament. The output from the carrier oscillator will increase with increasing plate potential, and due to the above characteristic may be made to compensate somewhat for the tendency of the gain of the modulating tubes to increase. Figure 31 shows the change in gain of the modulator circuit when the plate potential of either the oscillating or modulating tubes is changed independently. With these arrangements the total variation in the modulator or demodulator gain, due to the fluctuations of power supply, does not usually exceed ± .25 TU. The possible variation due to tube differences is somewhat larger, approximately ± .7 TU. This is not serious since tubes are ordinarily replaced when a system is out of service, and the gain can be readjusted before the system is restored to operation.

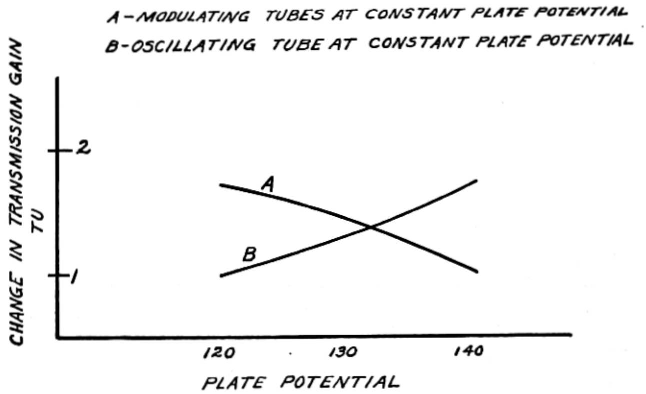

Figure 31—Modulator gain—relation to plate potential

Another requirement which the modulator must meet is one of transmission quality or equality in transmission gain at various frequencies in the voice band. The modulator should not limit the band of frequencies which are to be transmitted over the system. In other words, the gain of the modulator should be substantially the same for frequencies between 200 and 2,800 cycles per second. The characteristics of the transformers and the impedance in which the output of the modulator is terminated are the controlling factors in the quality of the modulator. A typical characteristic of modulator gain with frequency under ideal terminations is shown in Figure 32.

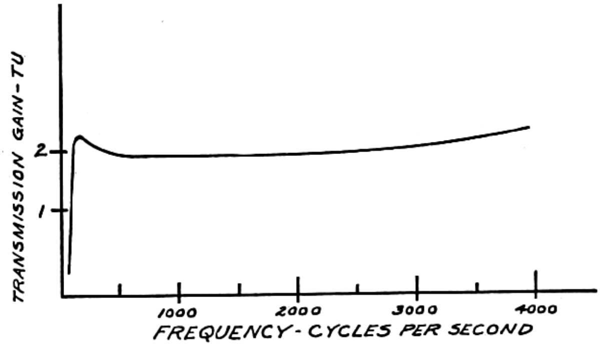

Figure 32—Modulator gain—relation to frequency

In the type "C" system the effect of the band filter impedance is to cause a variation in this characteristic of approximately 5 TU at 2,800 cycles.

The final requirement placed upon the modulator relates to the energy level which must be handled. It should not be possible to overload the modulator seriously with the amount of power produced by a subscriber's set at the transmitting toll testboard level. With a given modulator circuit, this requirement can be met by designing the input transformer with the proper turns ratio.

The following paragraphs give a more detailed description of the actual circuit which has been developed to meet the above requirements.

The voice-frequency circuit is through the hybrid coil to the terminals of the input transformer. The resistance placed across the input circuit is to improve the impedance terminating this branch of the hybrid coil, and thus improve the terminal impedance looking into the hybrid coil from the voice-frequency line. The condenser C-1 is inserted in series with the primary winding of the transformer to improve the transmission characteristic of the circuit at low frequency. This condenser resonates with the inductance of the primary winding, increasing the voltage across the primary at low frequencies where the modulator input circuit tends to become less efficient. The two windings of the secondary side of the transformer are separated by by-pass condenser C-2, as they are at different potentials from ground, due to the series connection of the filaments of the vacuum tubes. The variable condenser C-3 affords a means of balancing the carrier frequency potentials. Condenser C-4 is one half the maximum capacity of C-3 in order that carrier frequency unbalance in either side of the circuit may be compensated for to a sufficient degree by means of the one adjustable condenser C-3. The voltages, E_1 and E_2, provide the grid bias for the modulating tubes V-1 and V-2. The condensers C-5 and C-6 provide a low impedance path around the source of biasing potentials for the carrier frequency, and condenser C-7 in the plate circuit performs the same function with respect to the plate battery.

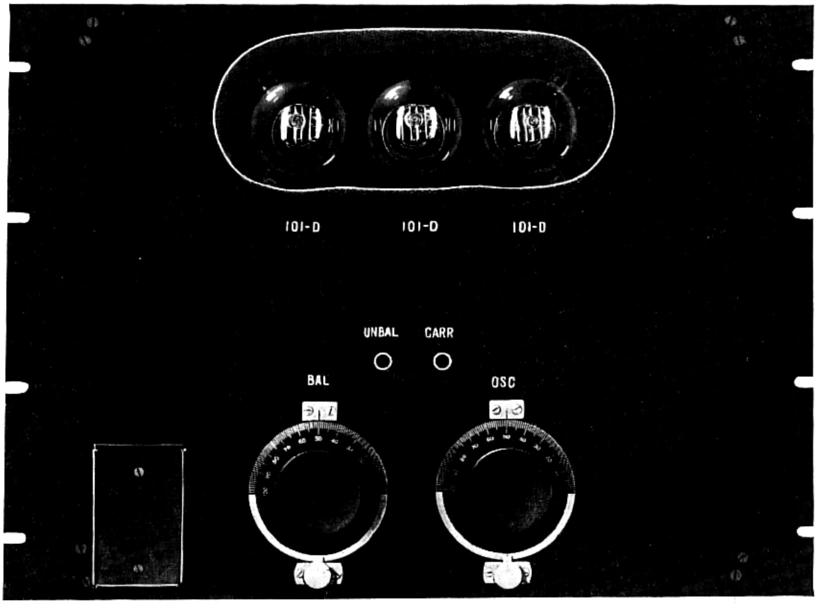

Figure 33—Assembly of modulator panel. (Front view)

In the oscillator, the condensers C-8 and C-9 together with the inductance of one winding of the transformer T-4 form the oscillating circuit. C-9 is made adjustable to compensate for manufacturing variations in the inductance, and to provide in addition a certain flexibility in frequency adjustment. A grid bias for the oscillating tube is provided by the grid leak-condenser combination C. The plate battery is connected through the retardation coil L-1, which presents a high impedance to the carrier frequencies, and prevents them from flowing through the plate battery. The carrier current in the plate circuit divides between two paths, one through R-2, the feedback resistance to the grid circuit, and the other through R-3, the output resistance, and the transformer T-2 which impresses the carrier voltage on the grids of the modulating tubes. The filaments of the tubes in the modulator circuit are wired in series, and the current flow is regulated by a ballast resister B.

Figures 33 and 34 show the front and rear views of the modulator panel. The adjustable condensers which control the carrier frequency and the carrier balance are accessible from the front of the panel. In the rear view, the oscillator circuit occupies the left-hand side of the picture. The oscillating transformer is in the upper left-hand corner, with the oscillating condensers directly below it. The feedback and output resistances are connected across the top of the panel. The oscillating tube is left of the three tubes, and the carrier input transformer is below it. The voice input transformer is to the right of the carrier transformer, and the output transformer is located in the upper right-hand corner. A metal cover fits over the complete panel at the back to provide electrical shielding and mechanical

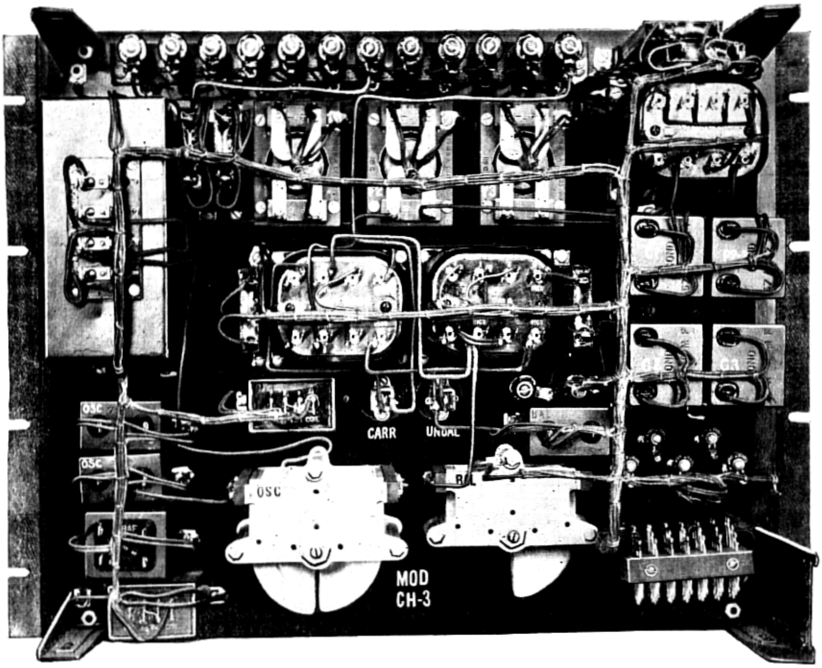

Figure 34—Assembly of modulator panel. (Rear view)

protection. All outside connections to the panel are made through the terminal block in the lower right-hand corner. Wires supplying power, together with those which are at a low a.-c. potential with respect to ground, are run in a cable, while wires at a high a.-c. potential are run directly from point to point in as short a path as possible in order to reduce losses resulting from the capacity of these wires to ground.

Demodulator and Receiving Oscillator. The circuit of the demodulator shown in Figure 35 is in many respects similar to that of the modulator. The function performed by the demodulator is also similar, being a translation from a high-frequency band to a lower instead of the reverse.

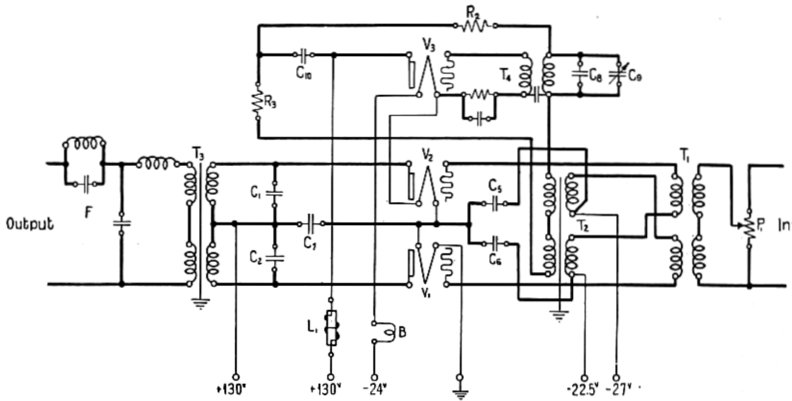

Figure 35—Schematic of demodulator circuit and receiving oscillator

The oscillator which supplies the carrier to the demodulator is of the same type as the modulator oscillator, and has been discussed in connection with that circuit. No adjustable feature for balancing the carrier is required in the demodulator circuit. The carrier suppression needed in addition to the suppression inherent in the balanced circuit is provided by the low-pass filter at the output. If the carrier is not sufficiently suppressed, it will pass into the voice circuit or across the hybrid coil into the associated modulator, causing in some channels an objectionable beat tone.

The transmission stability of the demodulator is obtained by the same methods used in the modulator since the performance of the two circuits is similar, and the transmission quality requirement is essentially the same for both units. A typical demodulator characteristic is shown in Figure 36. This characteristic at the higher frequencies is controlled by the low-pass filter.

One feature which is required with the demodulator, but not with the modulator, is a variable control of the transmission gain of the circuit. Due to the unequalized transmission of the line section adjacent to the terminal, or other differences in the channel equivalents, the three sideband currents normally arrive at a receiving terminal with unequal strength. A potentiometer controlling the gain of the demodulator permits of an equalization of the overall losses on the three channels.

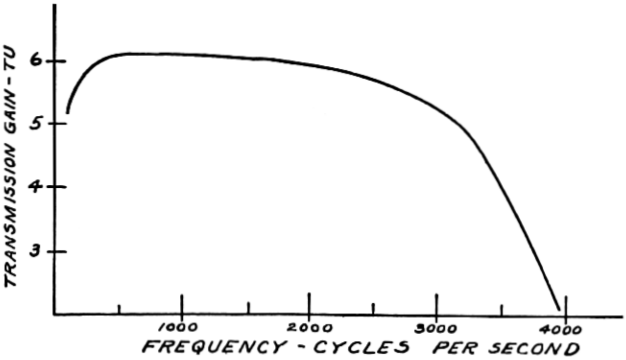

Figure 36—Demodulator characteristic—gain and frequency

In the following detailed description of the demodulator circuit other minor differences between it and the modulator may be pointed out:

The sideband frequencies enter the demodulator passing to the potentiometer P-1 which controls the amount of current to the input transformer T-1. The position of the carrier input transformer T-2 is somewhat different in the demodulator circuit as compared to the modulator circuit, due to the difference in the high-frequency characteristic of the T-1 transformers. In the modulator this transformer must be designed to transmit voice frequencies primarily. It has a comparatively large capacity to ground which would reduce the effective carrier voltage on the tube grids if it were placed in the same circuit position as is the demodulator transformer. The function of most of the circuit elements is evident from the previous description of the modulator. The C-1 and C-2 condensers provide a low impedance path for the carrier frequency. They are necessary here because the transformer T-3 designed for high efficiency at voice frequencies has considerable leakage inductance, which would present a high impedance to the carrier in the plate circuit if the condensers were not provided. For the maximum gain the impedance of this circuit should, of course, be a minimum at carrier and sideband frequencies. At the output a low-pass filter structure F provides for the suppression of the unwanted products of demodulation.

A front view of the demodulator unit is shown in Figure 37. The panel layout and general appearance is similar to that of the modulator. The two dials shown control the demodulator input and the oscillator frequency, respectively, as indicated in these figures.

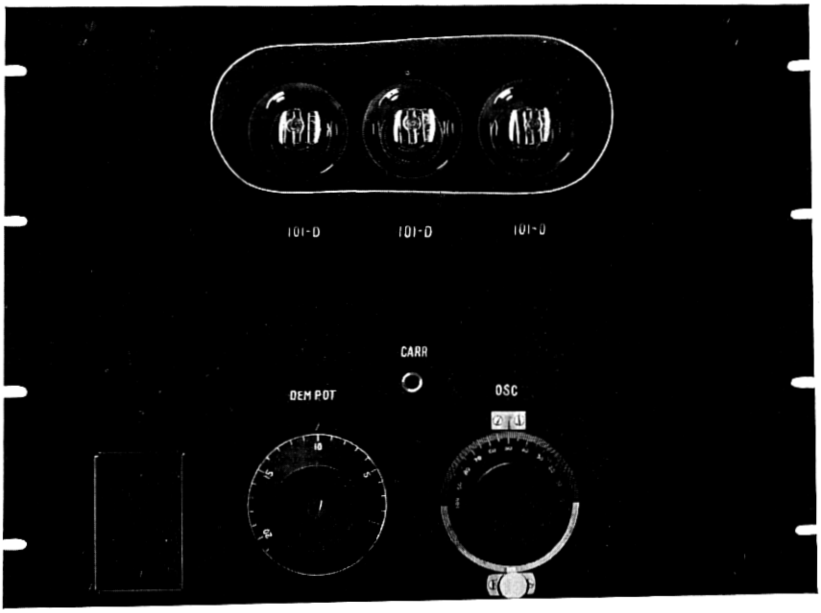

Figure 37—Assembly of demodulator panel. (Front view)

Filters. The general function of a band filter is the selection of a band of frequencies, and the protection of this band from interfering frequencies located on either side. The filters determine what band width is transmitted, and thus to that extent they control the quality of speech which may be obtained through the carrier circuit. The type "C" system transmits a band corresponding to approximately 200 to 2,700 cycles per second in the voice range.

In considering the requirements imposed upon the band filters it is necessary to keep in mind [9] the fact that the modulator produces not only the particular sideband which is to be transmitted but also an unwanted sideband of the same volume as the wanted sideband and

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[9] R. V. L. Hartley, "Relation of Carrier and Side Bands in Radio Transmission," *Bell System Tech. Jl.*, V. 2, April 1923, pp. 90–112.

equal to it in width, located on the opposite side of the carrier frequency. In addition to these products of modulation there are produced other frequency bands, the important ones occupying sideband positions about the harmonics of the carrier frequency. See Figure 38.

The first requirement on the band filters is imposed by the need of suppressing the unwanted sideband to prevent distortion when the carriers are out of synchronism. The tests mentioned above in connection with the oscillator frequency stability were made with but one sideband transmitted. If both sidebands are transmitted, the carriers must be exactly in synchronism or a "wobble" due to the demodulation of both sidebands can be detected. One sideband must be suppressed by an increasing amount as this carrier difference increases. For a carrier frequency difference of about 20 cycles it is necessary to suppress the unwanted sideband about 40 TU, thus reducing it to about 1/100 of the strength of the wanted sideband in order to eliminate completely this type of distortion. This requirement can be met by providing the necessary attenuation in either the transmitting or the receiving band filter, or by making the sum of their attenuations equal to 40 TU.

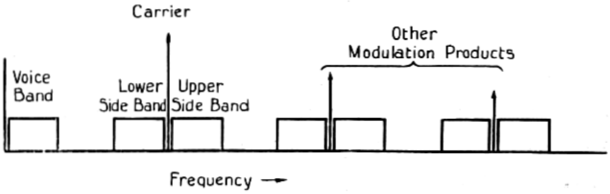

Figure 38—Frequency range of products of modulation

The suppression of the unwanted sideband is necessary for another reason in a multi-channel system in which the transmitted sidebands are close together. The unwanted sideband from one channel overlaps the wanted sideband of an adjacent channel, and would be demodulated and appear as "crosstalk" into this channel if it were not suppressed by the transmitting band filter. The suppression needed is determined by the amount of interference which can be tolerated from one channel to another. It has been found that to meet this requirement the transmitting band filter must suppress the unwanted sideband about 60 TU. The other modulation products mentioned above must also be reduced by the transmitting band filter to a value which will not cause interference in any channel into which they might pass. The discrimination requirement for these frequencies is less severe because the magnitude of these modulator products is not so great.

A particular termination is required at the end of the filter which is connected to the modulator. In order to get the maximum sideband power out of the modulator used, the impedance of the associated band filter, seen from the modulator, must be made low over the range of voice frequencies.

With the channels placed closely together and with the coordination of different types of systems, depending upon the channel locations, it is important that the band filters remain constant after manufacturing, and that all filters of the same type be manufactured to meet close requirements. For proper coordination between systems it has been found desirable to keep all the channel bands within ± 125 cycles of an assigned location. This means in the higher frequency channels that the filters must be manufactured to a frequency accuracy of the order of 1/2 of 1 per cent.

The attenuation requirements for the receiving band filter are somewhat different from those of the transmitting band filter. The purpose of the receiving band filter is the suppression of the frequencies of the adjacent channels as they are received over the line. In contrast to the transmitting filter, which must suppress the unwanted frequencies produced in its own channel, a filter with somewhat different characteristics could, therefore, be used for a receiving filter. While the requirements were determined separately for the receiving and transmitting filters, it was desirable in the interest of manufacturing economy to build both alike, setting requirements on the basis of a double purpose filter. Thus, this filter had to provide attenuation at each frequency to meet the more severe of the requirements for either the transmitting or the receiving position. Figure 39 shows the transmitting characteristic of a typical filter designed to meet the requirements outlined above.

As has been explained, the grouping of the channel bands in opposite directions requires the use of so-called directional filters at terminal and repeater points. These filters occur in the circuit in pairs—each pair consisting of one high-pass and one low-pass filter. The "cut-off" point of the filters is determined by the type of system in use—C-S or C-N and its corresponding "grouping point." At repeater points the filters are split for each direction in order to provide selectivity at both the output and input circuits of the amplifiers.

Considering the closed circuit through the two amplifiers and the four directional filters, the attenuation in this loop must be considerably greater than the sum of the gains of the two amplifiers at all frequencies. In the regions outside of the carrier frequencies, the margin between attenuation and gain is made about 10 T. U. For frequencies in the carrier range this margin must be still greater to prevent distortion, which becomes objectionable when circulating currents of any size are allowed to exist. This "feed-back" effect will also affect the repeater input impedance, and because of the necessity for closely controlling this characteristic the margin between gain and attenuation is not permitted to be less than 25 T. U. at any frequency used for transmission in either direction. The impedance of these filters on the line side must match the line impedance closely in order that no considerable reflection of the carrier currents can take place at this junction point.

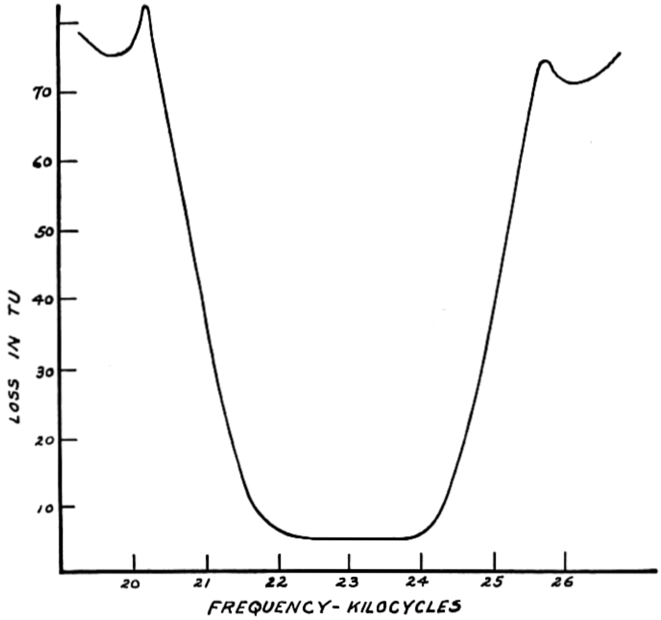

Figure 39—Typical band filter characteristic

As was mentioned previously, the output of an amplifier contains, due to modulation, other frequencies in addition to those which compose the input, so that crosstalk is to be expected between some of the channels. The amount of this crosstalk, which will appear at the far end, depends on the ratio of the sideband currents to the interfering currents produced in the amplifier, the measurement being made at the repeater output. The near-end crosstalk, however, is dependent on the level difference between the strong output of the one amplifier and the weak input to the other. Those frequencies which may give trouble in the channels at the near end enter the returning circuit at the amplifier input, a point where the sideband level is very low. To put the near-end crosstalk on the same basis as the far end, the output directional filter must introduce enough attenuation in its non-transmitting range to make up this level difference. This attenuation is increased until the near-end crosstalk due to this cause is appreciably less than the far end.

The output current of one amplifier may be 30 TU or more stronger than the input current to the amplifier for the opposite direction, and the directional filter at the input of this second amplifier must offer sufficient attenuation to the output currents of the first so that they will not contribute materially to its load.

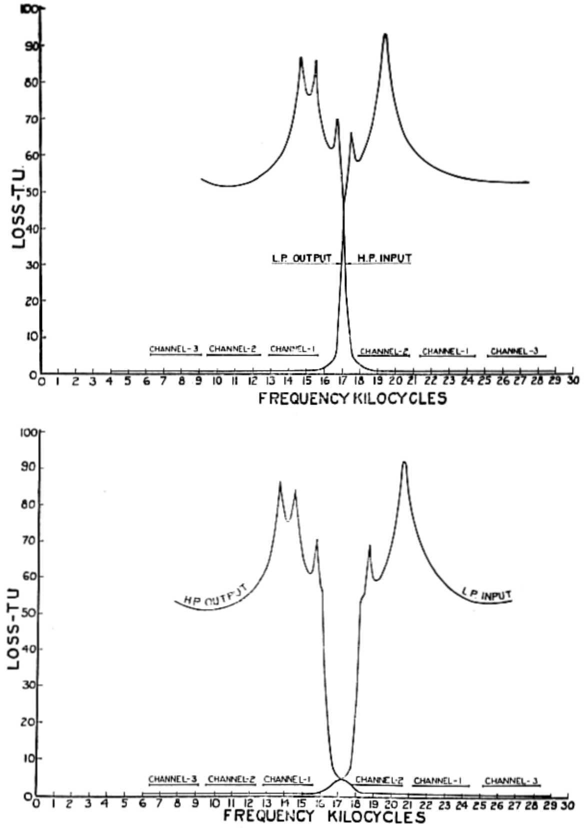

Figure 40—Typical directional filter characteristics

Figure 40 shows the selectivity characteristics of the two directional filters.

A pair of filters having important functions is the line filter set which, as has been noted, acts to separate the carrier currents from the regular speech currents on the common line circuit. It consists of a high-pass and a low-pass filter paralleled on the line side. Currents entering these terminals from the line circuit pass through the high-pass circuit to the carrier apparatus or through the low-pass circuit to the circuit terminal or repeater. The transmission characteristics of these filters are shown on Figure 41. It will be noted that frequencies above approximately 3,300 cycles are transmitted in the high-pass circuit and frequencies below about 2,800 cycles are transmitted through the low-pass circuit. It is common to equip a few line circuits with line filter sets, in addition to those which are normally in use for carrier transmission. This makes it readily possible in case of an emergency or for other reasons to use the spare wires thus equipped for carrier transmission.

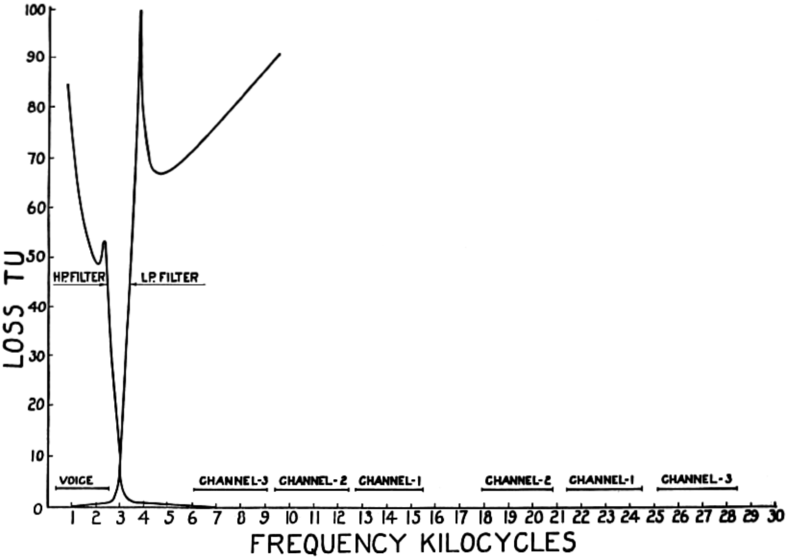

Figure 41—Typical line filter characteristics

Non-linear effects may be produced in the coils and condensers in the circuit. The design of the filter parts must be made so that these effects will be a minimum. This requires the use of non-magnetic cores in the coils, and also that the containers be of non-magnetic material. Condensers in magnetic containers must be located so that they will not lie in the field of the coils and thus contribute to the modulation products. The modulation in the line filters, telegraph composite sets, and office and cable loading units, must also be considered.

As already mentioned, care has to be exercised in the mounting of filters belonging to different systems in the same office, so that no crosstalk will be introduced from one system into another. A considerable level difference may exist between two filters of different systems, and it may be desired to mount these filters on adjacent bays. In order that the crosstalk between these two systems may be kept within desirable limits, the separation between the filters must, in some instances, correspond in attenuation loss to the order of 120 TU, or one part in a million. To meet this exacting requirement, the filters are totally incased in sealed copper boxes, the leads being brought out through small holes to terminal blocks.

Amplifiers. As previously mentioned, the amplifiers employed with the type "C" system at the terminals are identical with those used with the repeaters at intermediate stations. The following is, therefore, applicable to both cases:

The number and size of tubes needed to deliver the necessary output level or power are largely controlled by interchannel crosstalk requirements. With the grouping frequency arrangement, the three bands which transmit in the same direction are amplified in a common circuit. The different sideband frequencies in passing through the common amplifier must not react upon each other to produce other frequencies of sufficient magnitude to cause interference. For example, second harmonics of the lowest band frequencies lie within the range of the highest channel in the lower group. If these harmonics are permitted to become too great, troublesome noise will be present in the highest channel when speech currents flow in the lowest. In order that this interference or crosstalk may not become excessive the tubes used in this amplifier must be made of ample power capacity.

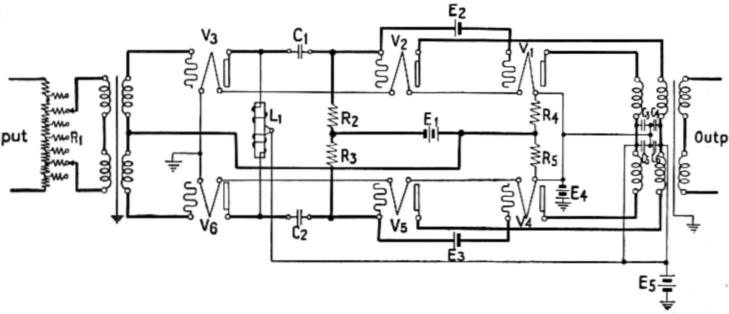

Figure 42—Amplifier circuit

This example of interference caused by the second harmonic shows the desirability of using a push-pull amplifier in carrier repeaters because of its property of balancing out second order effects, which in a single tube or unbalanced circuit are the largest of all the modulation products at the usual loads.

The currents from the three channels enter the carrier amplifier shown in Figure 42. The circuit consists of two stages; the first stage of two tubes, the second of four of higher power rating. The gain is controlled in 2 TU steps by the adjustable potentiometer in the input. The gain frequency characteristics for different potentiometer settings are substantially flat within a small fraction of a TU over the range of any channel.

The amplifiers for the two directions are of slightly different design, each amplifier being arranged for a flat characteristic over its own group of frequencies. It has been stated that the load capacity of the amplifier is limited[10] by the modulation products which increase with the load. Figure 43 shows the amount of second and third harmonics produced in a typical repeater with varying single frequency output. By connecting the tubes in push-pull instead of in parallel, the second harmonics have been reduced by about 15–20 TU. Other products of modulation as well as the second and third harmonics increase with the output and thus the power which can be taken from the amplifier under the operating conditions is limited as these effects are likely to result in interchannel interference.

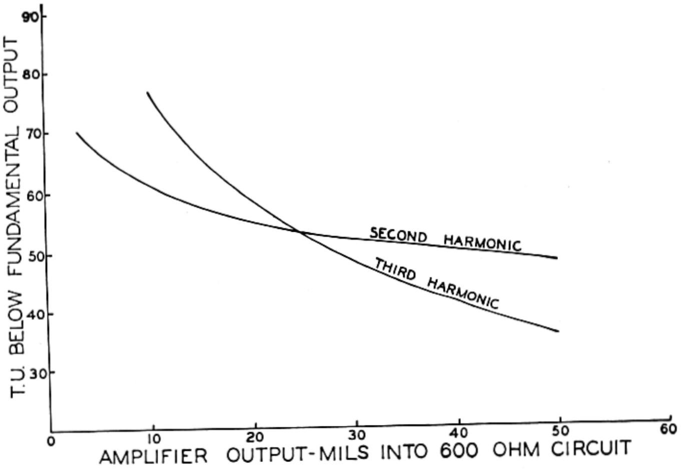

Figure 43—Amount of second and third harmonics as function of carrier repeater output

When the alternating voltage applied to one grid is positive with

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[10] F. C. Willis and L. E. Melhuish, "Load Carrying Capacity of Amplifiers," *Bell System Tech. Jl.*, V. 5, October 1926, pp. 573–592.

respect to the filament, that on the other grid is negative. Since the even order products are proportional to an even power of the input voltage, these currents will flow through the high side winding of the output transformer non-inductively producing no flux in the transformer, and hence no current in the low side windings. To realize this ideal condition, the two currents flowing in the output transformer windings must be equal in amplitude, and 180 degrees out of phase. Like amplitudes can be obtained in several ways since the plate current is a function of a number of tube constants. Tubes may, therefore, be selected which will give the same harmonic current, that is, tubes in which the net effect of the several factors is the same.

Conclusion

Use in Telephone Plant. The carrier systems are meeting successfully and economically the requirements of long distance telephone service. From what has already been written, it is evident, however, that the apparatus is by its nature complex and to a fair degree expensive, so that for the relatively short distances it is cheaper to string additional wire. The exact distance beyond which it is more economical to employ carrier methods is obviously dependent on the circumstances surrounding each particular case. Systems are operating for distances of 150 miles and upwards.

Traffic growth often requires additional circuits for the shorter distances, where there are longer haul continuous physical circuits on the same line. In this case it is not uncommon to break up the long haul physical circuits into sections to satisfy the short haul circuit growth and to install a carrier system to meet the long haul needs.

The growth of the use of carrier systems has already been pictured. How the systems are distributed over the lines of the Bell System is shown on Figure 44. The heaviest density of use occurs in the middle and western sections and in general where the circuit demand and growth have not reached the large figures required to justify the installation of toll cables. In particular, the section west of the Mississippi is a promising field for the application of carrier systems.

Future. While the type "C" system satisfies those circuit growth demands for moderate and long haul, there has remained undeveloped a considerable field for carrier methods over the shorter distances where only wire stringing has hitherto been economical. Very recent developments have resulted in the trial and early field applications of a simple single-channel carrier telephone system designed particularly to meet these shorter haul demands and thereby to secure the greatest practicable economy in providing facilities by carrier methods in the

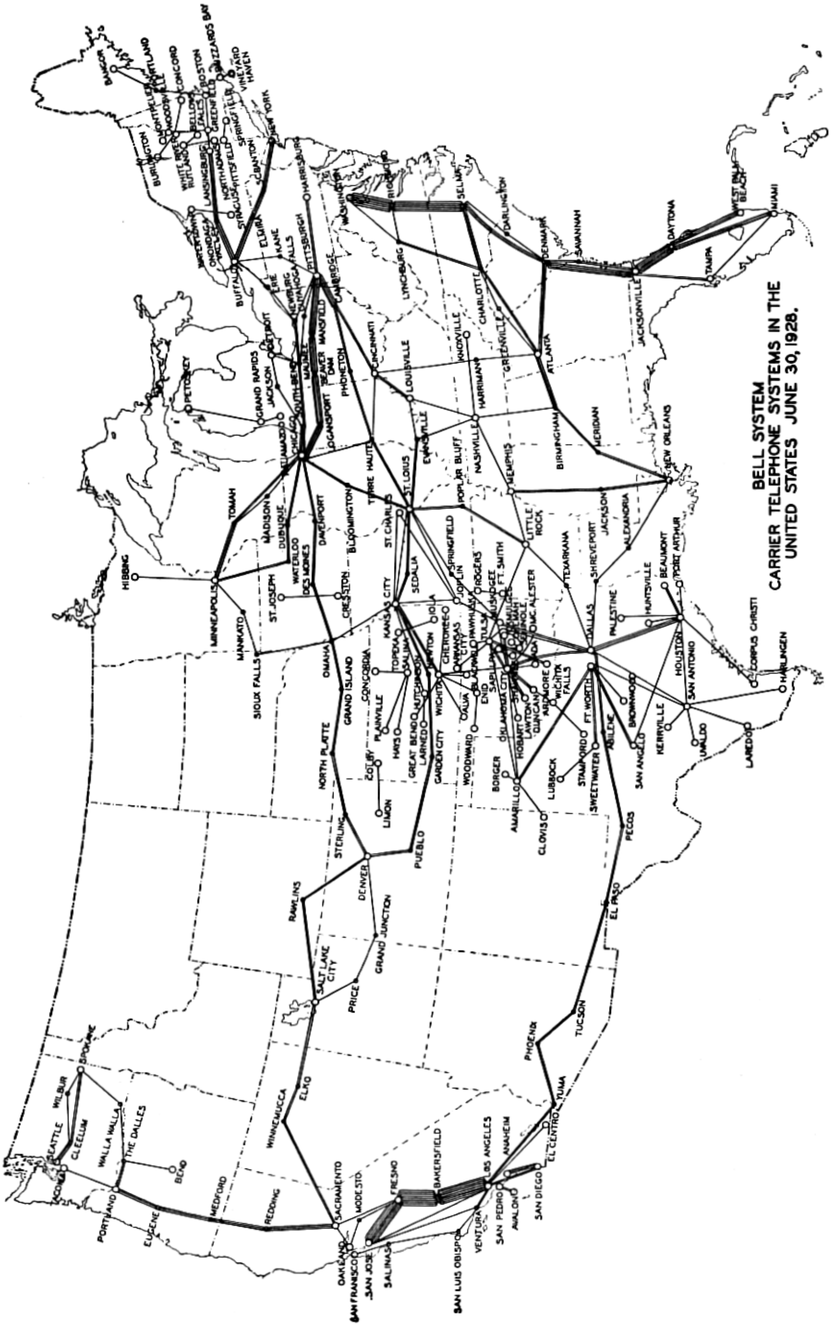

Figure 44—Map showing carrier telephone systems throughout Bell System

Bell System. It is naturally finding its most extensive use in the sections of the telephone plant where the shorter circuits predominate. Because of the fact that the type "D" system development is only now being completed it was thought desirable in the present paper to confine attention to the long haul system (type "C") and to defer the presentation of the detailed information on the short haul development until a somewhat later date.

While considerable progress has been made in the development and application of these carrier systems since the beginning of their use about ten years ago, there is still much to be done in the matter of simplifications and further use of the high-frequency spectrum. Automatic pilot channel arrangements are being tested whereby manual maintenance costs can be reduced. Further developments are anticipated in the matter of transposition arrangements to permit an open-wire line to carry multi-channel long haul carrier systems on most of its pairs. While the systems now in use in the field employ frequencies no higher than approximately 30,000 cycles, frequencies considerably higher than this can undoubtedly be economically employed.

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