Carrier Telephony on High Voltage Power Lines

By W. V. WOLFE

Introduction

THE use of power from hydro-electric generating stations and central steam plants has increased until single companies serve a territory of many thousands of square miles and the problem of coordinating the distributing centers with the generating stations has steadily increased in complexity.

One of the essentials of this coordination is obviously an adequate system of communication and until the recent advent of high frequency telephony, this service was secured over privately owned telephone lines and over lines of public service telephone companies.

The advent of the power line carrier telephone system now offers a highly reliable and satisfactory means of communication in connection with the operation of power systems. This equipment has been designed to employ the power conductors as the transmission medium and to provide service as reliable as the power lines themselves with a low initial cost, a small maintenance charge, increased safety for the operating personnel and transmission comparable in quality and freedom from noise with that obtained on high grade commercial toll circuits.

Preliminary Problems

In proceeding with the development of the Western Electric Power Line Carrier Telephone System three major problems were encountered. It was first necessary to learn from field tests and close contact with power companies the characteristics of power lines and associated apparatus at high frequencies and the operating requirements for such a telephone system; second, it was necessary to develop a safe and efficient method for coupling the carrier apparatus to the power conductors and third, to select and develop circuits and equipment suited to this service.

The superiority of the full-metallic over the ground return high frequency circuit was easily established by comparative measurements of attenuation, noise and interference, and therefore the experimental work was largely confined to the former circuit.

High Frequency Attenuation of Power Lines

Since the measurement of the attenuation of a circuit ordinarily requires that the circuit be terminated in its surge impedance [1] to avoid reflection effects, the first step in determining the attenuation of the power line was to measure its surge impedance. After considering several methods for measuring this impedance, a substitution

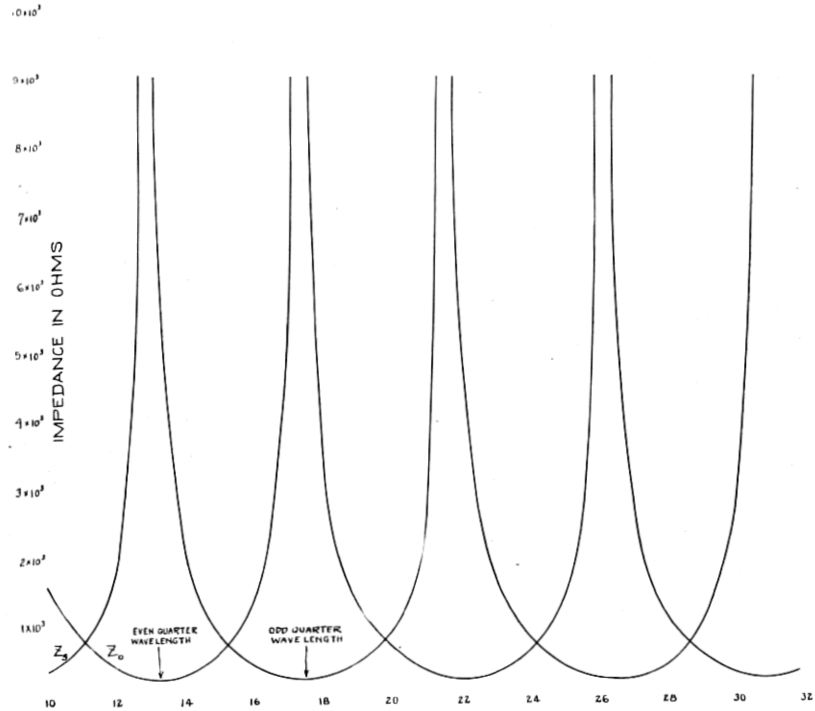

Fig. 1—Open Circuit (Z_o) and Short Circuit (Z_s) Impedance as Measured at Carrier Frequencies on a 110,000 Volt Power Line 12 Miles Long

method was adopted because of its simplicity and the rapidity with which measurements could be made. This method depends upon the fact that the apparent or measured impedance of a uniform line terminated in its surge impedance is equal to that surge impedance and it consists in terminating the line in a known resistance and determining the value of current supplied to the line by an oscillator

[1] Surge or characteristic impedance may be defined as the measured impedance of a uniform line of infinite length or in the case of a finite line it may be expressed mathematically as $Z=\sqrt{Z_{\substack{\text{open}\\ \text{circuited}}} \times Z_{\substack{\text{short}\\ \text{circuited}}}}$

and then substituting for the line a non-inductive resistance until the same value of current is drawn from the oscillator. In employing this method for determining the surge impedance it was assumed that the oscillator output was constant, and that the phase angle of the surge impedance was small.

A study of the curves on Fig. 1 shows that the apparent impedance of the line will change with the impedance in which the line is terminated in different ways, depending upon the frequency used. (1) If

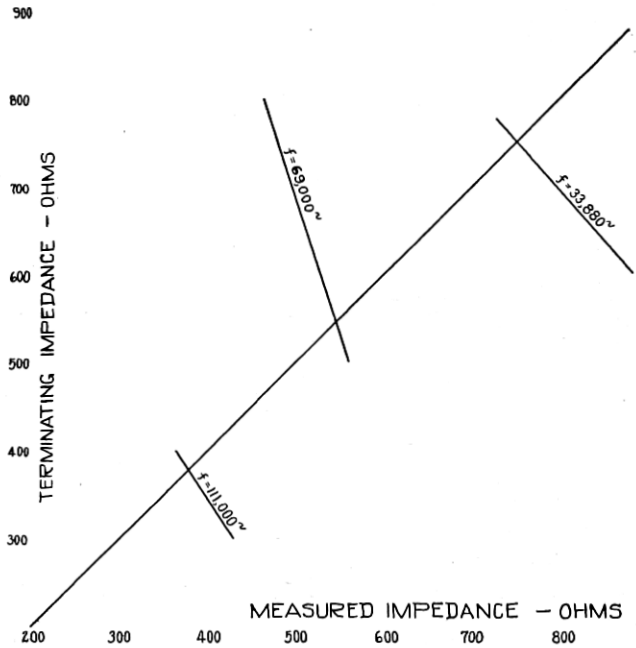

Fig. 2—Graphical Solution of Substitution Method for Determining the Surge Impedance of a Power Line

a frequency mid-way between the quarter wave lengths[2] is used, the open circuit and short-circuit impedances are the same. (2) If a frequency corresponding to an even quarter wave length is used, an increase in the terminating impedance will produce an increase in the apparent impedance of the line. (3) If a frequency corresponding to an odd quarter wave length is used, an increase in the terminating impedance will produce a decrease in the apparent imped-

[2] Whenever the length of the line becomes equal to, or some multiple of, one quarter of the length of the electric wave of the corresponding frequency, it is referred to as a quarter wave length frequency, or, for short, a quarter wave length.

ance of the line. If the apparent impedance of the line is plotted against the terminating impedance, in (1) the curve will be horizontal; in (2) the curve will have a positive slope approaching 45° and in (3) the curve will have a negative slope of approximately 45°. Each of these curves will intersect a 45° line drawn through the origin at a point where the terminal impedance is equal to the surge impedance of the line. This intersection can be determined with the

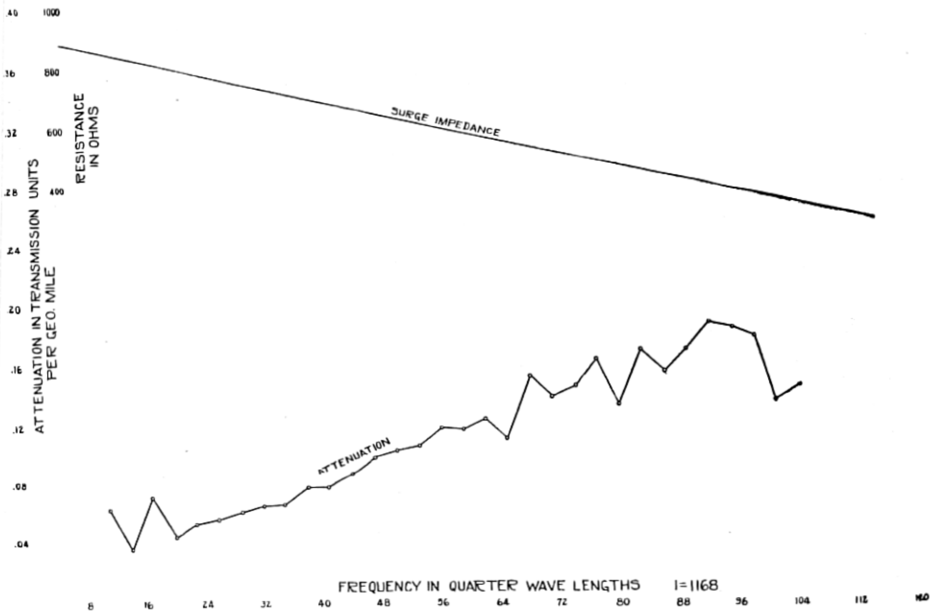

Fig. 3—Frequency vs. Attenuation and Frequency vs. Surge Impedance as Measured on the Tallulah Falls-Gainesville 110,000 Volt Power Line

greatest ease and accuracy when the curve crosses the 45° line at right angles or under condition (3), that is, when the determination is made at a frequency corresponding to an odd quarter wave length. To determine the surge impedance at a given frequency all that was necessary was to terminate the line at the distant end in an impedance which it was anticipated would be just below the surge impedance and measure by the substitution method the apparent impedance of the line, and then to terminate the line at the distant end in an impedance which would just exceed the surge impedance and determine the corresponding apparent impedance. The intersection of a straight line through these points with the 45° line determined the correct terminating impedance. In Fig. 2 is shown a determination of the characteristic impedance of the Tallulah Falls-Gainesville line of the Georgia Railway and Power Company at three different frequencies.

The attenuation of the line was then measured by terminating it in its characteristic impedance and measuring the current in to the line and current out of the line.[3] The results of the attenuation measurements made on the Tallulah Falls-Gainesville line are shown on Fig. 3. The irregularities in the attenuation shown by the lower

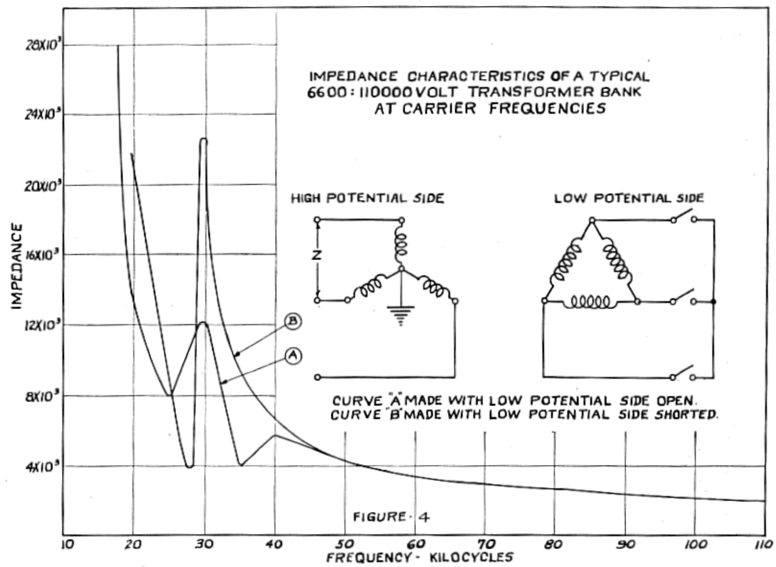

Fig. 4—Impedance Characteristics at Carrier Frequencies of a Typical 6600:110000 Volt Transformer Bank

curve are probably caused by the error in assuming that the phase angle of the surge impedance was small and that the surge impedance was a straight line function of frequency. From these and other data it was evident that for frequencies as high as 150 K.C. the attenuation is not excessive.

High Frequency Characteristics of Power Transformers

In order to determine the effect of power transformers on the use of the power line as a transmission medium for high frequency currents,

[3] Attenuation expressed in transmission units is equal to $20 \log_{10} \frac{I_1}{I_2}$ where I_1 is the current into the network and I_2 is the current received from the network and measured in a circuit whose impedance corresponds to the characteristic impedance of the network.

the impedance of typical transformer banks was measured. In Fig. 4 is shown the impedance versus frequency characteristic of a three phase, 110,000–6600 V., 12,000 K.V.A. transformer bank connected "star" on the high side with the neutral grounded and "delta" on the low side. As shown by the diagram, these measurements were made between phases on the high side with the low side open circuited and short circuited. The coincidence of these curves for frequencies above 50 K.C. indicates that at these frequencies the dominant characteristic is the distributed capacity of the high winding and the impedance is probably unaffected by changes on the low potential side of the transformer. Below 50 K.C., however, the impedance changes rapidly both with frequency and with the low potential termination.

A study of Figs. 3 and 4 and other data shows that the desirable frequency range in which to operate a power line carrier telephone circuit is that from 50 K.C. to 150 K.C. In this range the attenuation is not excessive, it is very little affected by the associated power apparatus, and it is independent of the conditions on the low potential power circuits. The curve shown in Fig. 3 indicates that, contrary to the common belief, the attenuation in this range is a relatively smooth function of frequency. This conclusion is supported by the fact that in the various installations of power line carrier telephone equipment which have been made since the attenuation measurements on Fig. 3 were obtained, no power lines have been encountered where the attenuation was a critical function of frequency. Another important argument for the selection of this frequency range lies in the fact that it is well above the range employed for multiplex telephony on commercial telephone systems and therefore precludes any interference with such systems.

Coupling Between Carrier Equipment and Power Line

Probably the most difficult problem to solve was that of providing a satisfactory method for connecting the carrier equipment to the power line. The use of power transformers has not been found practicable for if frequencies low enough to be efficiently transformed were employed, the attenuation of the circuit would be a function of the conditions in the distributing network and a change in the number or arrangement of transformers would result in an appreciable change in the attenuation. Such a method of coupling to the power line would also have the objection that communication would not be possible when the power transformers were disconnected from the line.

Since it did not seem practicable to develop a carrier frequency transformer suitable for connecting between phases of a high voltage power line it was decided to couple to the power line by means of capacity. Two general types of condensers are possible, first, a concentrated capacity condenser and second, a distributed capacity condenser. A concentrated capacity condenser suitable for direct connection to a high voltage power line was not available, but its development has been successfully undertaken by the Ohio Brass Co.

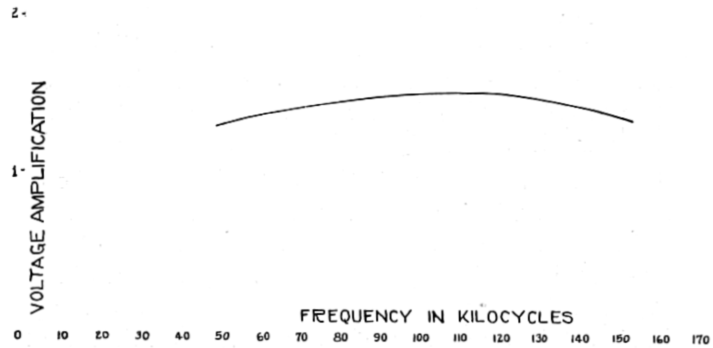

Fig. 5—Voltage Amplification Characteristic of High Frequency Transformer

The distributed capacity was obtained by suspending a wire parallel to the power conductor and employing this wire as one plate of the condenser and the conductor as the other plate. Both of these methods of connecting to the power line have been developed and are described later.

Design of the Carrier Equipment

Although the "carrier suppressed" system has many advantages over the "carrier transmitted" system, the difficulty of securing filters suitable for suppressing the unwanted products of the modulation prevented the use of the carrier suppressed system.

Several general characteristics of the electrical and mechanical design of this carrier equipment are worthy of note. The various stages of vacuum tubes in both the transmitting and receiving circuits are coupled by transformers. These transformers are closed iron core coils using the standard core employed for audio-frequency transformers. Fig. 5 shows the characteristic of one of these transformers, and it is evident from this figure that the variation in amplification from 50 K.C. to 150 K.C. is only a fraction of a transmission unit.

Although the frequencies employed by this equipment are fairly high, it was practicable to mount all of the apparatus on standard steel relay rack plates. In order to minimize the maintenance on this equipment no "C" batteries have been employed, the grid potentials

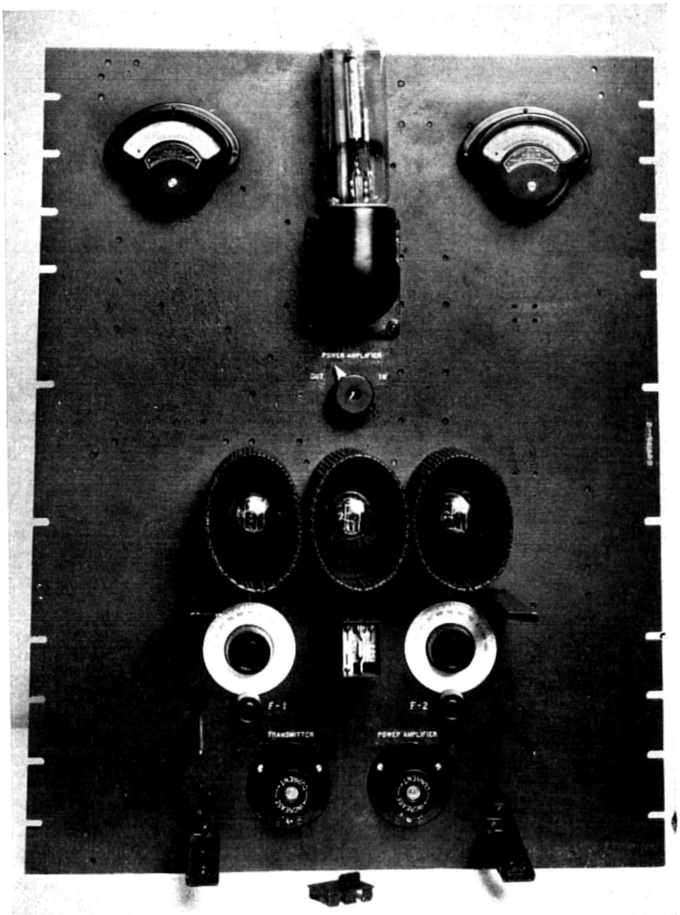

Fig. 6—Front View of Transmitter Panel with Cover Removed from Tuning Condensers

being obtained from filament drop, "B" battery drop and a combination of these two.

The transmitting unit shown in Figs. 6 and 7 is divided into two parts, the transmitting circuit proper and the power amplifier. The first is a circuit comprising a 101-D tube functioning as a Hartley oscillator with inductive feed-back, a 223-A tube operating as a speech amplifier or modulator and a 223-A tube operating as a high frequency amplifier. The plate or constant current system of modulation is employed but differs somewhat from the usual practice in

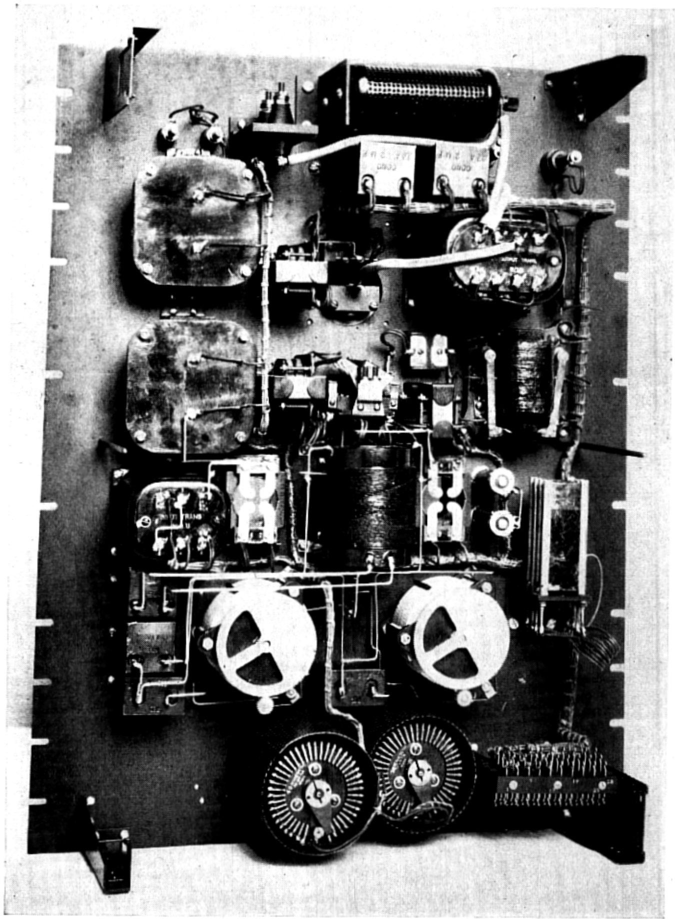

Fig. 7—Rear View of Transmitter Panel with Cover Removed

that the output of the high frequency amplifier is modulated rather than the output of the oscillator itself. This scheme was found to deliver more modulated power than the usual arrangement since it is not limited to the same extent by the overloading of the high frequency amplifier. This circuit has a power output of one watt, which has proved to be ample for normal operation of the carrier system.

To provide for operation of the system when the attenuation on the power line has been materially increased by line fault conditions a power amplifier is provided. This amplifier employs a 50 watt tube (211-A) and is placed in the circuit by a simple switching operation. When this amplifier is operated, the output of the transmitting circuit is impressed upon the grid of the 50 watt tube and amplified to approximately fifty times its normal power output.

In the present type of carrier system duplex or two way operation is secured by the use of two different carrier frequencies, one for transmission in each direction. As will be pointed out later in the

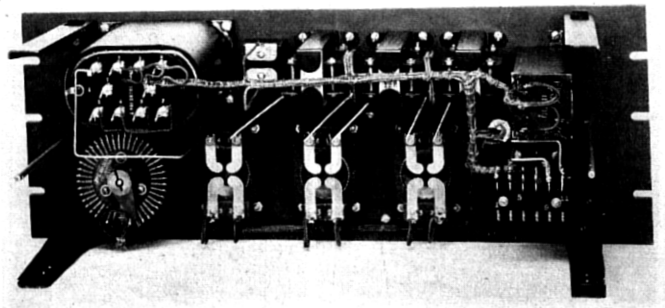

Fig. 8— Rear View of Receiver Panel

section on signaling the lower frequency is always assigned to the calling station. The transmitting circuit must therefore operate at two different frequencies. This change is accomplished by the automatic operation of the relay shown in Fig. 6. The operation of this relay changes the capacity in the oscillating circuit, thereby changing its frequency. The values of the two frequencies at which the transmitting circuit operates are determined by the variable condensers F1 and F2, Fig. 6, and certain fixed condensers which are connected in parallel with the variable condensers.

The receiving unit shown in Fig. 8 is extremely simple. It is not tuned and the only control is the filament rheostat. It consists of three 101-D vacuum tubes operating respectively as a carrier frequency amplifier, a negative grid potential detector and an audio frequency amplifier.

Two way operation is secured by operating the transmitting and receiving circuits at different frequencies and separating them by means of filters. In the single channel systems this separation is secured by a high pass filter and a low pass filter although in the multiple channel system band pass filters will be employed. Fig. 9 shows attenuation versus frequency characteristics of the high and low pass filter combination. A study of these curves shows that the transmission loss or attenuation in the high pass filter to frequencies transmitted by the low pass filter is never less than 90 T.U., which corre-

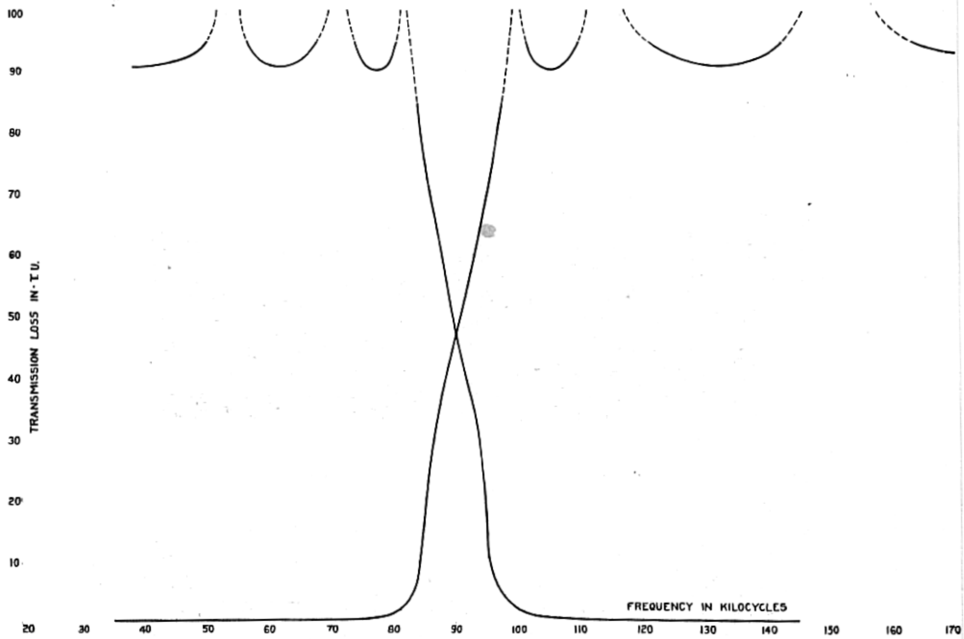

Fig. 9—Transmission Characteristic of High Pass and Low Pass Filters

ponds to a current ratio of approximately 30,000 or a power ratio of approximately 9×10^8, and the attenuation in the low pass filter to the frequencies transmitted by the high pass filter is also equal to or greater than 90 T.U.

The characteristics of these filters are remarkable when it is considered that the frequency range in which they operate is higher than that employed for multiplex carrier telephone systems, the attenuation secured is higher than that ordinarily required for such systems, and a power of 50 watts has to be transmitted through them thereby introducing special problems in the design of the coils and condensers. Figs. 10 and 11 are front and back views of one of these filters.

One of the unusual features in the use of these filters is the fact that the position of the filters in the circuit is changed from time to time by the operation of the relay shown on Fig. 11, that is to say, when the transmitting circuit is operating at a frequency lower than 80 K.C. the low pass filter is connected to it and when the transmitting circuit is operating at a frequency higher than 100 K.C. the high pass filter must be connected to it.

Signaling System

Signaling or ringing is accomplished at the transmitting end by changing the frequency of the oscillator from a frequency below 80 K.C. to a frequency above 100 K.C. without changing the filters. This is

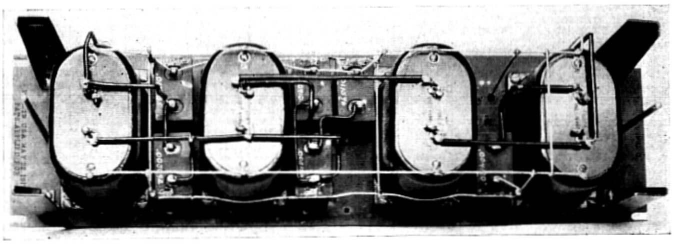

Fig. 10—Front View of Low Pass Filter with Cover Removed

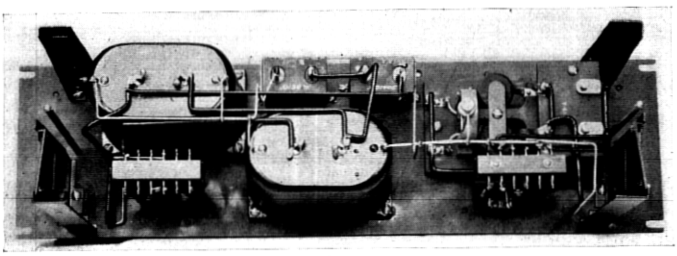

Fig. 11—Rear View of Low Pass Filter with Cover Removed

accomplished by operating and releasing the relay in the oscillator circuit. Since the filter connected to the transmitting circuit will pass only one of these frequencies, pulses of the carrier frequency are sent out on the line. At the receiving end these pulses are amplified and rectified and the change in the space current of the detector operates a marginal relay. The number and arrangement of these pulses is controlled by a spring-operated selector key of the type commonly employed for telephone dispatching on railroad lines. At the receiving end these pulses operate a train dispatching selector relay (see Fig. 12) which responds to 17 impulses. This selector relay will respond to only two arrangements of these 17 pulses. The first arrangement is 17 consecutive pulses in which case these pulses must follow one another at the correct speed and must be of the correct duration. This makes it possible to ring all stations at the same time as may be desirable in issuing general orders. The selector relay will also respond to 17 pulses broken up into three groups in which case the correct number of pulses must occur in each group and the total of the three groups must be 17. This makes it possible to

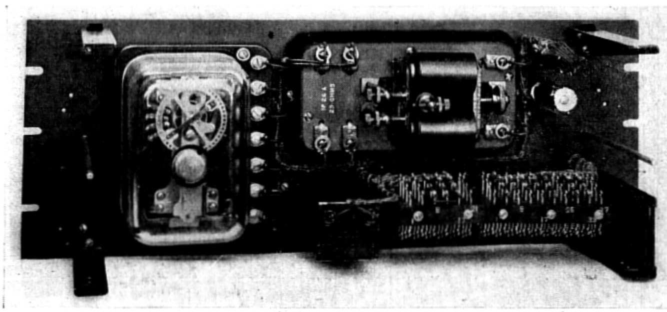

Fig. 12—Rear View of Signaling and Low Frequency Panel Showing the Signaling Apparatus

select one station from a group of more than 50 stations without disturbing the others. In addition to these desirable characteristics a single selector relay will provide selective ringing on four low frequency extensions from the carrier terminal.

The carrier equipment may be operated with complete control and talking facilities from either a telephone located at the carrier terminal or a telephone some distance from the carrier terminal but connected to it by a physical telephone circuit. In any event the control is automatic, the transmitting circuit operating only when the receiver is off the switchhook, while the receiving circuit operates continuously.

Designating the carrier frequency which is below 80 K.C. as F_1 and the carrier frequency which is above 100 K.C. as F_2, the operation of a carrier system comprising three carrier terminals designated as A, B and C with a remote control station designated as A_1 located at the load dispatcher's office and separated from the carrier terminal by several miles of physical telephone circuit is as follows. Each of these stations may communicate with any of the other stations. Communication between A, B and C is carried on over carrier circuits; communication between A and A_1 is carried on over the physical circuit while communication between A_1, B and C is carried on over circuits which are composed of a carrier circuit and a physical circuit operating in tandem. When in the normal or non-operated conditions, each of these carrier terminals is set up to receive a signal on frequency F_1, but when the receiver is removed from the switch-hook at any station to initiate a call, the carrier terminal corre-

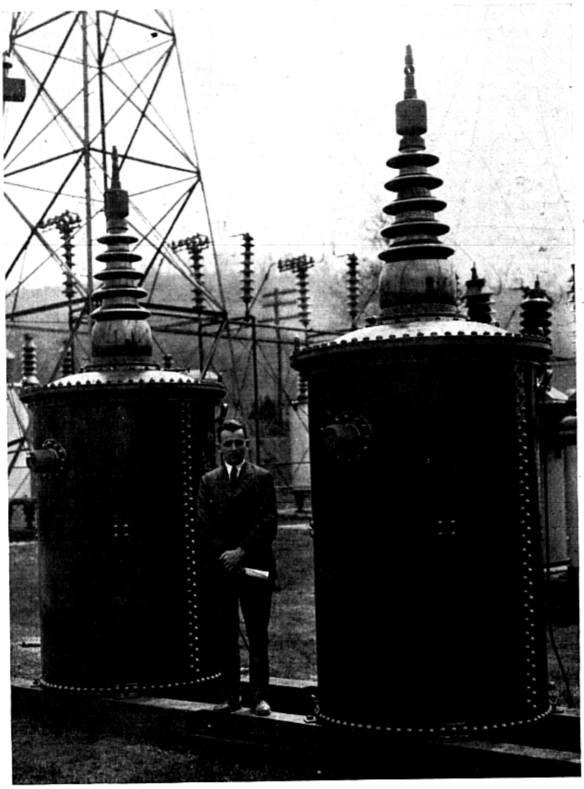

Fig. 13—110 K.V. Coupling Condensers Used for Coupling Carrier Circuit to a 110 K.V. Power Line

sponding to that telephone is automatically set up to transmit on frequency F_1 and receive on frequency F_2. When the ringing key is operated, pulses of frequency F_1 are sent out and received at all of the other carrier terminals. At the called station these pulses operate a selector relay and ring the bell, and when the operator removes his receiver from the switch-hook to answer the call, his carrier terminal is automatically set up to transmit on frequency F_2 and receive on frequency F_1. This switching of the transmitting and receiving circuits from one frequency to another is necessary where more than two stations are operated on the same system and it is desirable for every station to be able to call every other station without routing the call through a central point.

If station A_1 is connected with station A by means of two or more pairs of telephone wires which are not exposed to high voltage power

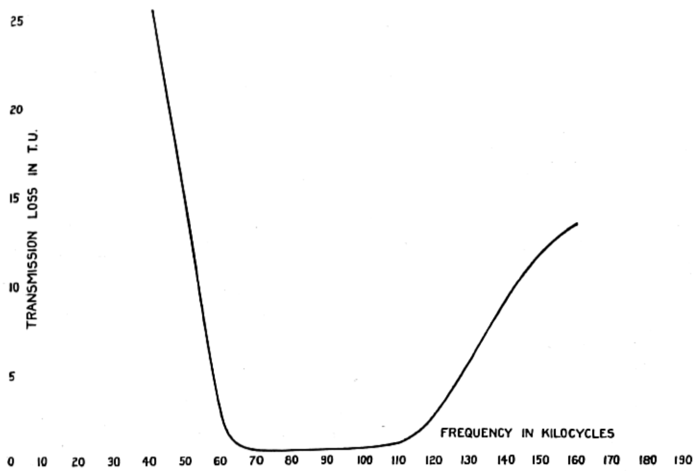

Fig. 14—Transmission Characteristic of Coupling Band Pass Filter

lines, a simple D.C. remote control circuit may be employed. However, if only two wires are available or if the telephone lines to be used are exposed to high voltage power lines and must therefore be equipped with insulating transformers and drainage coils, it is necessary to employ a somewhat more complex alternating current control circuit. In this circuit the 135 cycle interrupters and relays familiar to the telephone plant are employed.

The voice frequency circuits used in connection with this carrier equipment are the standard two wire and four wire circuits used in commercial telephone practices.

Coupling by Condensers and by Distributed Capacity

Fig. 13 shows two of the 120 K.V. coupling condensers developed by the Ohio Brass Co. Each of these condensers has a capacity of .003 μf although similar condensers having a capacity of .007 μf are also available. These condensers are approximately 5 ft. in diameter and 12 ft. high over the bushing and weigh about 8,000 pounds. The condenser element is made up of a large number of small condensers in parallel, the assembly being immersed in transformer oil.

At present these condensers are employed as the series capacity element of a single section, confluent type, Campbell band pass filter as shown by Fig. 22, the general attenuation characteristic being shown by Fig. 14. This filter is intended to transmit efficiently the carrier frequencies, and to exclude power frequency currents.

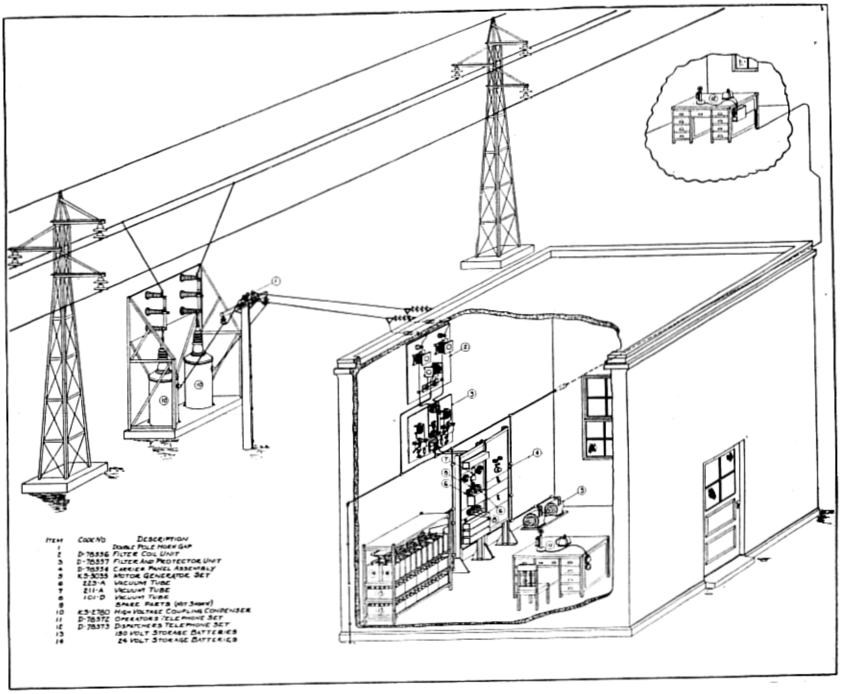

Fig. 15—Typical Layout of Power Line Carrier Telephone System, Using High Voltage Condensers for Coupling to Power Line

In Fig. 15 is shown a typical layout of a condenser coupled power line carrier telephone system.

In employing the distributed capacity type of condenser for coupling to the power line, two coupling wires (sometimes incorrectly called antennae) are suspended parallel to the power conductors for a distance of approximately 1,000 ft. Fig. 16 shows the last tower supporting the coupling wires in an installation at Anniston, Alabama. This is a twin circuit 110 K.V. power line and in order to secure coupling to both lines, the coupling wires are suspended midway between the top and bottom phases. The box shown on the tower in Fig. 16 is the coupling wire tuning unit shown in Fig. 17. The coupling wires are terminated in this tuning unit. In Fig. 18 is

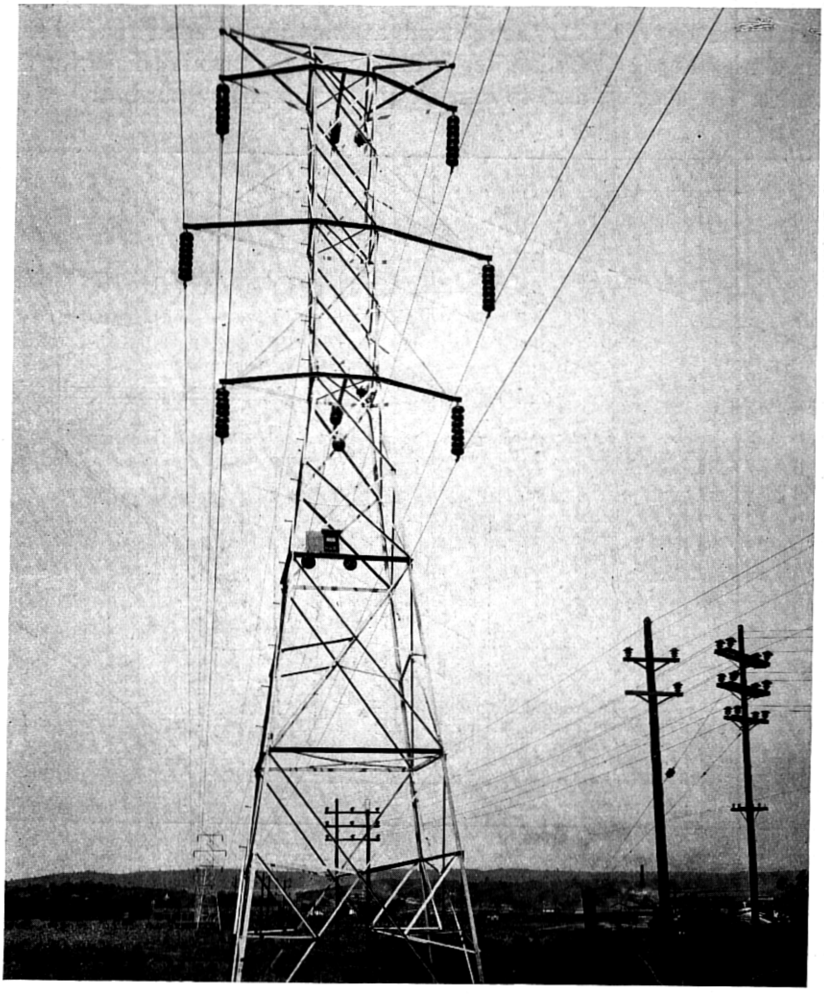

Fig. 16—Distant End of Typical Coupling Wire Installation Showing Coupling Wire Tuning Unit

shown the schematic diagram of the wire coupling circuit and Fig. 19 illustrates the character of the resonant peaks secured by this circuit. The series inductances L_1 and the terminating inductance L_2 are variable and by adjusting them the points of resonance may be shifted to correct for variations in the coupling wire inductance and capacity for different installations. Fig. 20 illustrates a typical carrier terminal installation employing the wire coupling method.

The only point in favor of the wire coupling as compared with the condenser coupling is the fact that for power lines of voltages higher

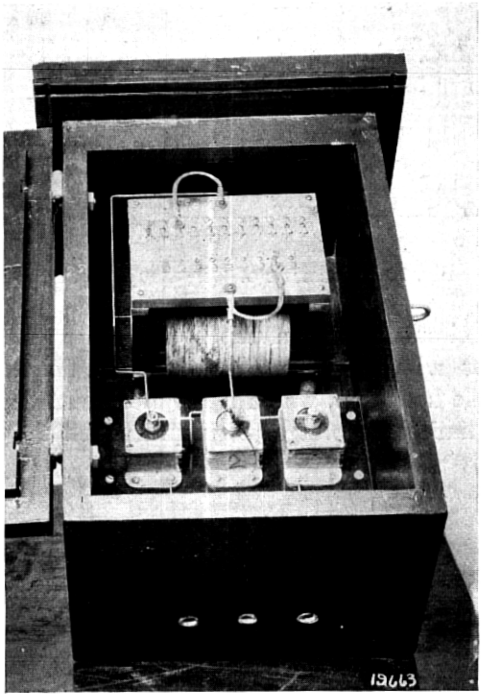

Fig. 17—Coupling Wire Tuning Unit

than 33 K.V. it is somewhat cheaper. On the other hand condenser coupling is much more efficient, thereby increasing the range and reliability of the system. It also permits high quality transmission, the transmission through it is not affected by small variations in frequency, and the component parts are of constant value determined at the time of manufacture and require no adjustment at the time of installation. In addition to these advantages the inspection and maintenance of the condenser is easier than for the coupling wires.

Protective Measures

In considering the problem of safety to the operating personnel and the equipment from the power line voltage, the normal insulation supplied by the high voltage condenser where it is employed or by the air separation where the coupling wires are employed, is disregarded, since this insulation may fail, thereby applying the power line voltage to the line terminals of the coupling circuit shown in

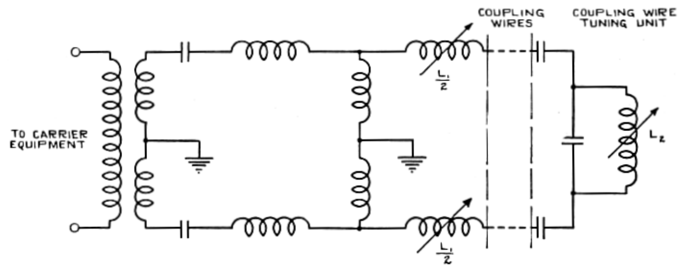

Fig. 18—Schematic of Wire Coupling Circuit

Fig. 21. The circuit shown in this figure is the same both for condenser and for wire coupling installations. The first element of protection is the horn gap, which is mounted outside of the building and serves to limit the voltage to ground which the drop wire fuse,

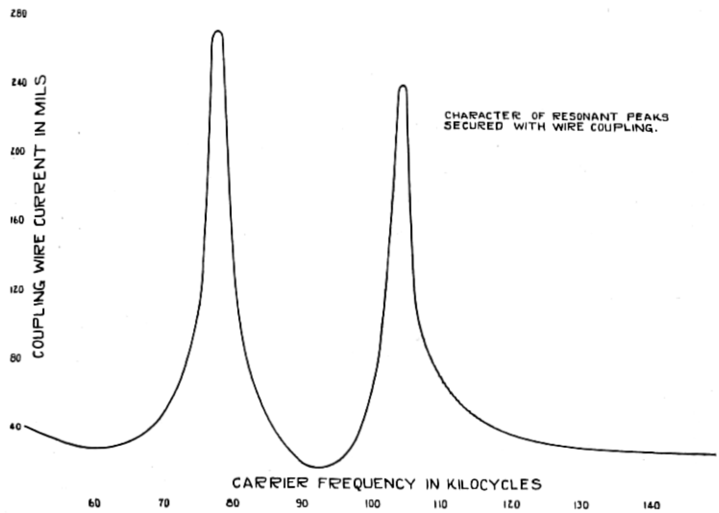

Fig. 19—Character of Resonant Peaks secured with Wire Coupling

constituting the second element of protection, will have to break. This fuse consists of an element inside of a porcelain tube the ends of which are closed by lead caps. This fuse is about 5 inches long and ½ inch in diameter and is supported by the wire itself. When it fails, the arc established within the porclain tube causes the tube to break and permits the wires to fall apart. In power line carrier telephone practice this fuse is so installed that a clear drop of at least 20 ft. is obtained. The third element of protection is the shunt coil with the mid-point grounded. In many respects this element is the

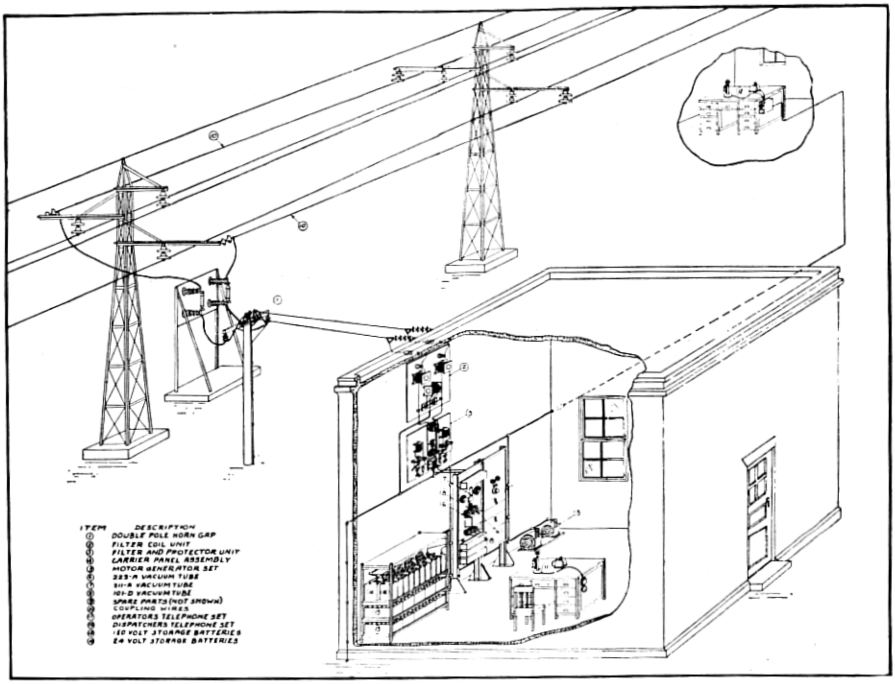

Fig. 20—Typical Layout of Power Line Carrier Telephone System Using Wire Coupling

most important one, since it provides a low impedance path to ground for power frequencies, thereby draining off the 60 cycle potentials which are collected by either the coupling wires or the condensers in normal operation.

As will be noted from Fig. 27 the line series inductances and this shunt inductance coil comprise a unit (the upper panel) which is known as the filter coil unit. The coils on this unit are insulated for 20,000 volts on the line terminals and are constructed of edgewise wound copper ribbon large enough to carry heavy momentary currents without damage. The fourth element of protection is a fused switch and surge arrester such as is commonly employed for the protection of private telephone lines exposed to power lines. This device consists of fuses in series with the line and forming the blades of a switch. These fuses have been found satisfactory for the interruption of voltages as high as 25,000. Following this fused switch is a 1,500 volt breakdown static spark gap to ground and a 500 volt breakdown vacuum gap

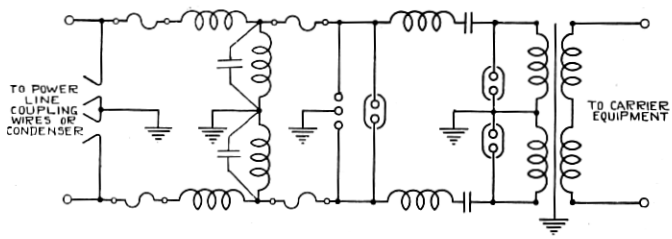

Fig. 21—Schematic of Protection Circuits

across the line. Following these there are two series capacity elements which are high voltage mica condensers. These condensers have a capacity of .007 μf. and a breakdown voltage in excess of 7,500. Finally, there is provided a repeating coil with the mid-point of the line side

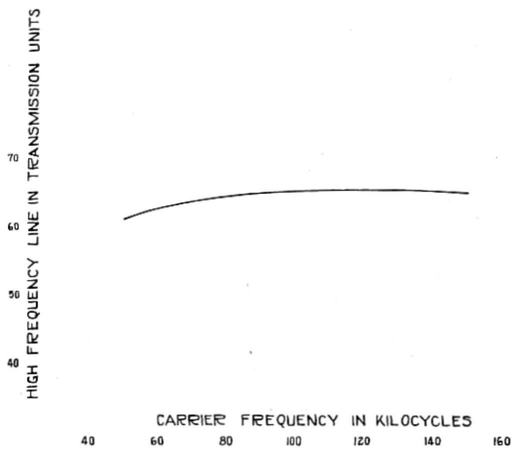

Fig. 22—Change in the Attenuation of the High Frequency Line Necessary to Maintain a Constance Voice Frequency Level with Variation in the Frequency of the Carrier

winding grounded and protected by 500 volt vacuum gaps to ground. This repeating coil is also provided with a grounded shield between the windings and has a breakdown voltage from the winding to the shield of 1,000 volts. The operation of this protective circuit has been demonstrated several times in the field by connecting one phase of a 110 K.V. power line directly to one of the line terminals of the protective circuit. In every case the circuit has operated satisfactorily. In no case has any of the standard apparatus been damaged nor has there been any evidence that the elements of protection beyond the third, that is, the shunt coil with the mid-point grounded, have been called upon to function.

Transmission Level Characteristics

Fig. 22 shows the attenuation (expressed in transmission units) of the high frequency line versus the carrier frequency of K.C. It will be noted that over the range from 50 K.C. to 150 K.C. the variation

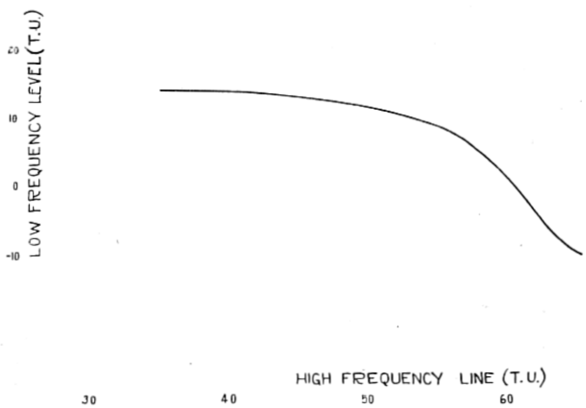

Fig. 23—Variation of Overall Gain with the Attenuation of the High Frequency Line

in attenuation is less than 5 T.U. This curve was made with a constant audio frequency input of 3.35 mils and an output of 3.35 mils from the carrier circuits, the audio frequency being 1,000 cycles. The variation of audio frequency level with the attenuation of the high frequency line is shown in Fig. 23. The observations given in Fig. 24 were made on an artificial transmission line in which the line constants, and therefore the attenuation, could be readily changed without changing the carrier frequency. The shape of this curve is a function of the receiving circuit since the audio input, carrier frequency and the modulated output of the transmitting circuit are maintained constant. It shows that for audio frequency levels lying between -10 and $+10$ T.U. the equivalent is approximately a straight line function of the attenuation of the high frequency line, and that therefore the receiving circuit is not overloaded.

Fig. 24 shows the audio frequency load characteristic. This curve is principally a function of the load characteristic of the modulator and it shows that for inputs greater than 1 mil, the modulator is overloaded. In practice the overloading of the modulator is prevented by increasing the average low frequency line equivalent to an attenuation of 10 T.U. by means of a resistance artificial line. This

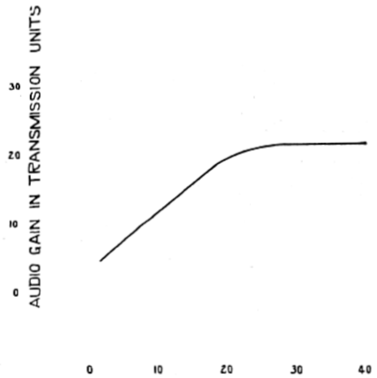

Fig. 24—Transmitting Circuit Load Characteristic

arrangement is desirable in order that the balancing of the low frequency hybrid coil may not be complicated when operating over very short physical circuits.

The curve in Fig. 25 is a single frequency quality characteristic and shows that where the method employed for connecting to the

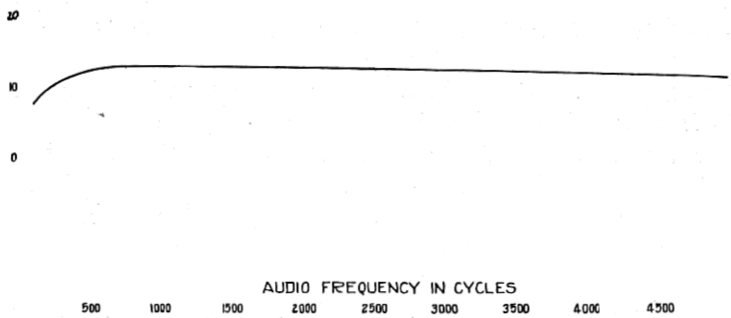

Fig. 25—Single Frequency Quality Characteristic

power line will permit, remarkably true voice transmission may be secured. The variation in the equivalent over the range from 100 cycles to 5,000 cycles is only 5½ T.U., while the variation from 300 cycles to 5,000 cycles is only 2 T.U. Reference to Fig. 19 will indicate, however, that less satisfactory quality characteristics are obtained when the wire coupling method is employed, because of the sharpness of resonance of the coupling circuit.

Alabama Power Company Installation

Figs. 26 and 27 are photographs of the installation of power line carrier telephone equipment at the Anniston substation of the Alabama

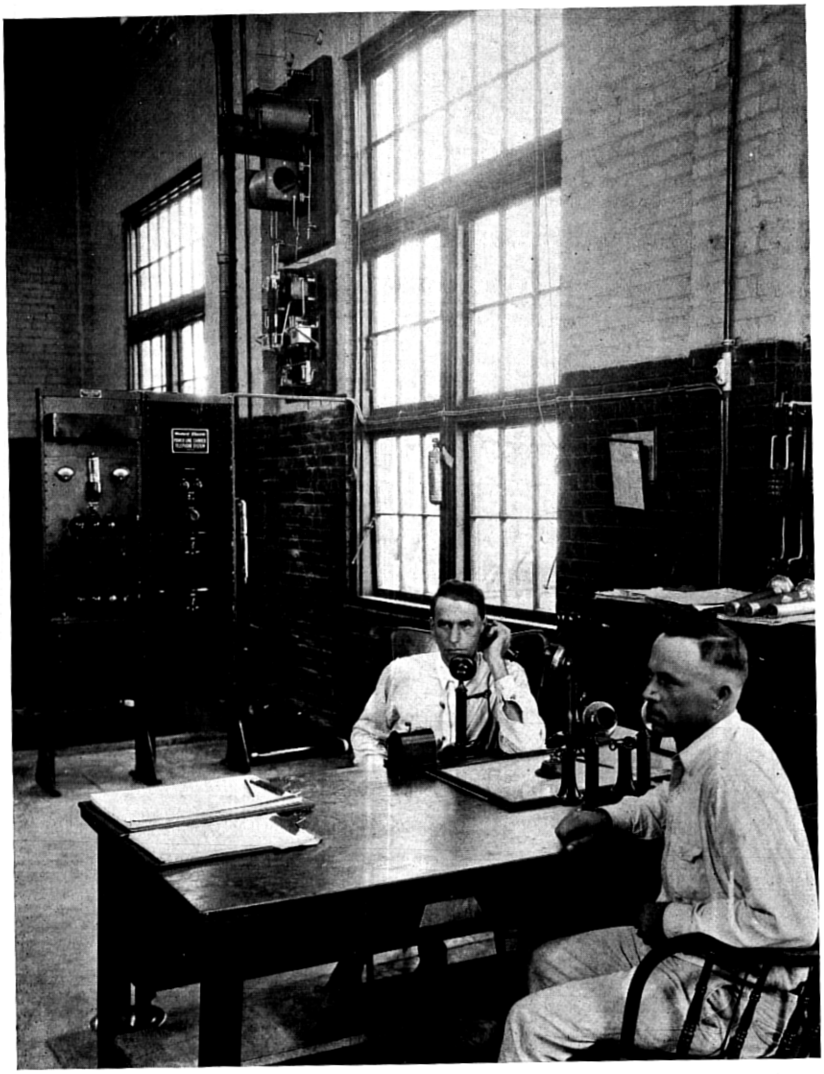

Fig. 26—Typical Power Line Carrier Telephone Installation

Power Company. Fig. 26 illustrates the simple character of the assembled units and freedom from controls. The right hand bay is devoted to power control apparatus with space reserved for the 135 cycle remote control equipment when it is employed. The left

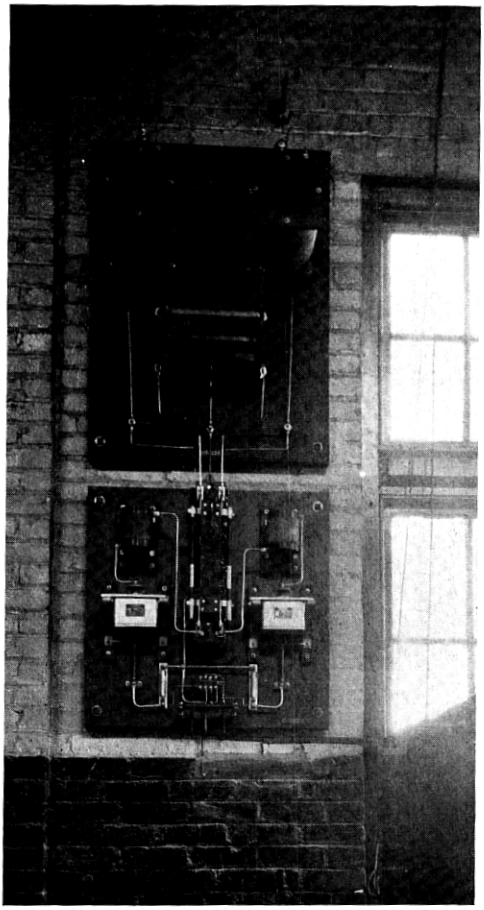

Fig. 27—Typical Installation of Coupling Panels

hand bay includes the transmitting and receiving circuits, the high and low pass carrier frequency filters and the voice frequency and D.C. control circuits. Beginning at the top of this bay, the first panel, which is blank on front, carries the system terminal. block to which all wiring except the power supply is connected. The second panel is the high pass filter; the third panel is blank. The fourth panel is the transmitting equipment, both low power and high power. The fifth panel is the receiving circuit; the sixth panel contains the voice frequency and signaling equipment. The seventh panel contains D.C. control equipment, and the bottom panel is the low pass filter. On the wall to the right of the carrier panel assembly are shown the filter coil unit and the filter and protector unit. These units are more clearly shown in Fig. 27 and diagrammatically in Fig. 21. Returning to Fig. 26, the desk stand which the operator is using is that associated with the carrier equipment, while the key mounted on the table immediately to the left of the desk stand is the selector key employed for ringing. Fig. 16 shows the coupling wire installation at this station.

The power line carrier telephone equipment which has been briefly described in the foregoing article is in successful operation today on several power systems in this country. Its reliability, simplicity of operation and maintenance have been well established.

The large number of variables which are involved in line failure conditions make it impossible to predict what effect these emergency conditions may have on the operation of the carrier equipment. The fact remains, however, that under many simulated and actual trouble conditions successful operation of the carrier equipment has been obtained.

With the growing need of power companies for communication facilities, it is probably only a question of a very short time before multiple channel carrier systems will be in operation on the large power systems of this country.