May 24, 1938. N. MONK ET AL 2,118,471

ELECTRICAL TRANSMISSION SYSTEM

Filed Sept. 1, 1932 3 Sheets-Sheet 1

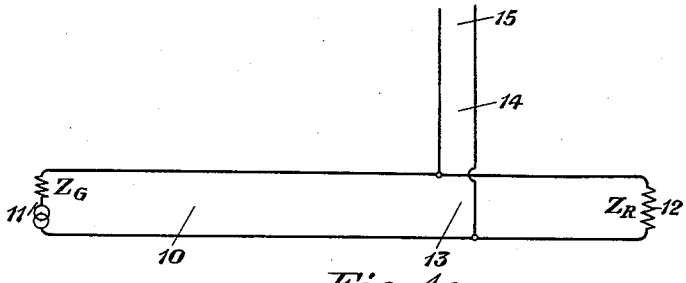


Fig. 1a

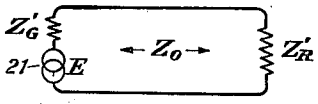


Fig. 1b

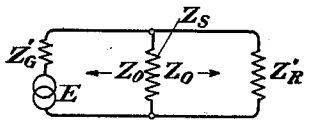


Fig. 1c

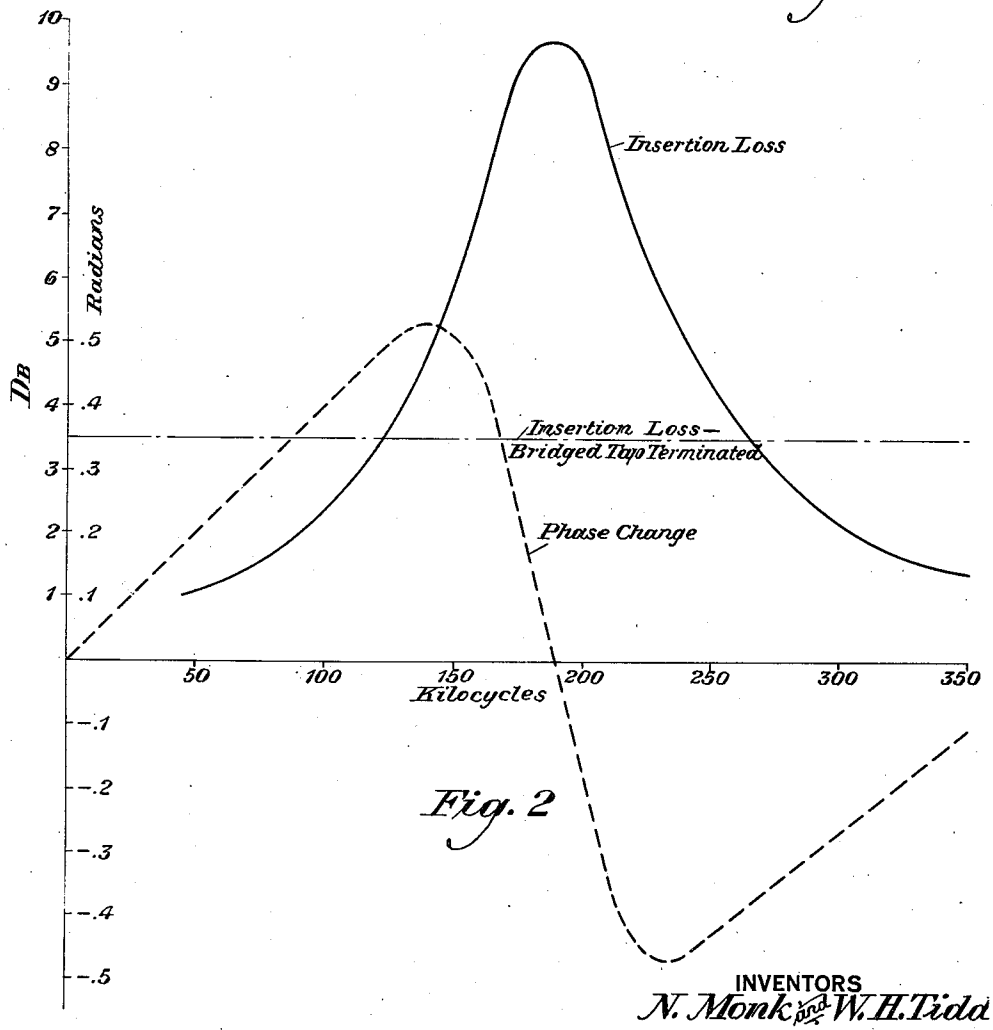


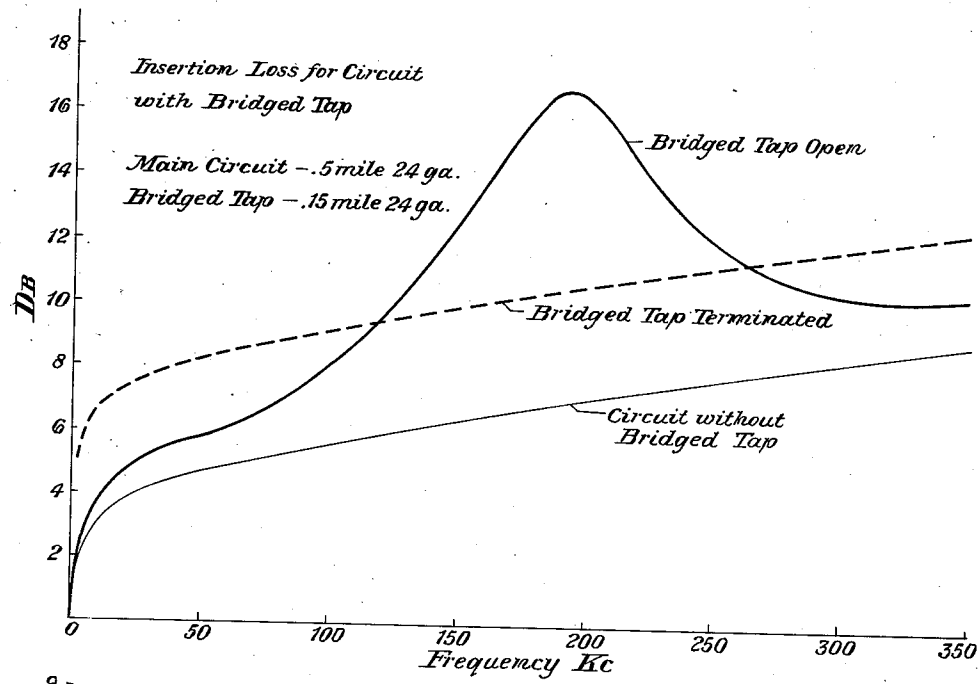
Fig. 2

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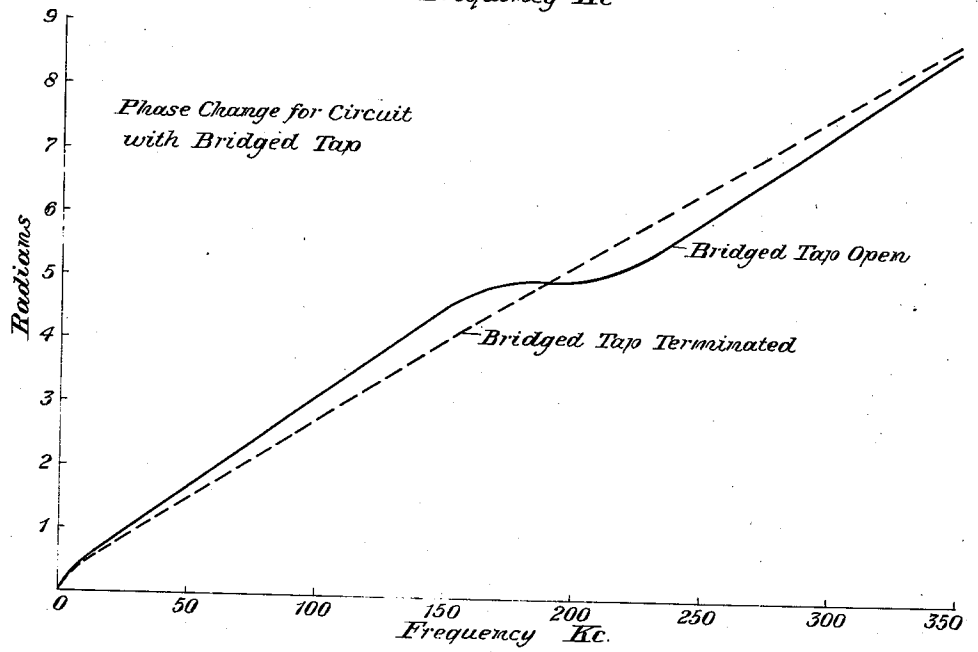


Fig. 3

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ELECTRICAL TRANSMISSION SYSTEM

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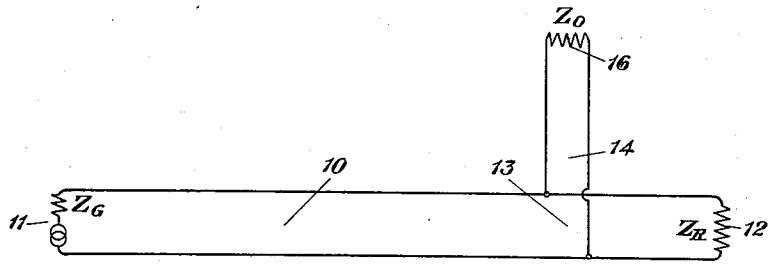


Fig. 4

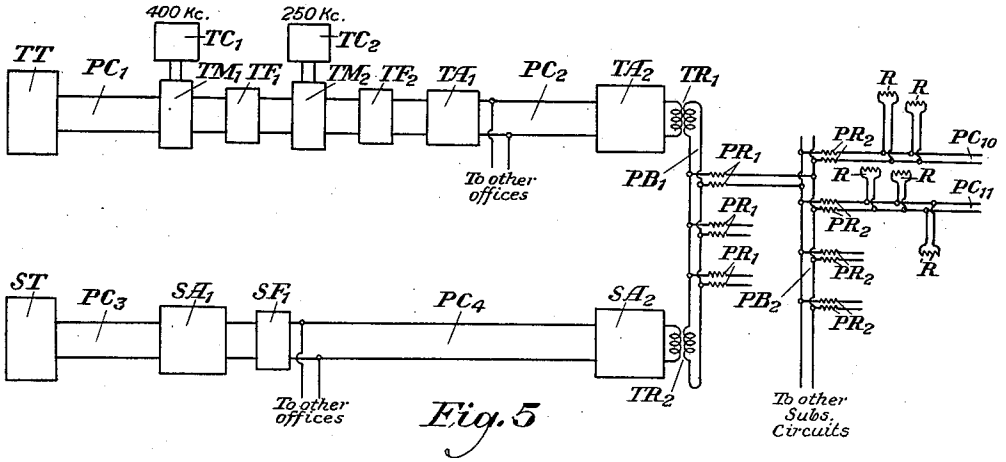


Fig. 5

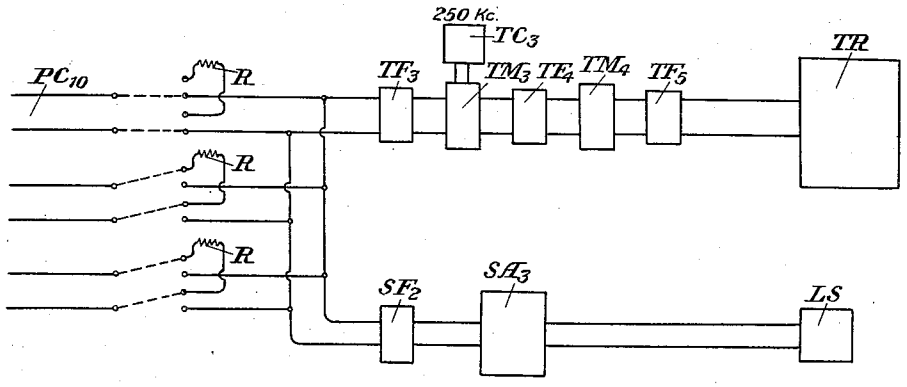


Fig. 6

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UNITED STATES PATENT OFFICE

2,118,471

ELECTRICAL TRANSMISSION SYSTEM

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Application September 1, 1932, Serial No. 631,408

5 Claims. (Cl. 178—5.6)

This invention relates to an electrical transmission system in which transmission is effected from a transmitting point to a receiving point over a circuit having connected to it one or more branch circuits which may be open at the distant end. One of the principal objects of the invention is the provision of means whereby undesirable reflection effects upon the main circuit, due to open-ended branch circuits, may be minimized.

For flexibility, most of the cable circuits in the telephone plant between the central office and the subscribers' premises are arranged to appear in several locations; thus any single circuit may have one or more branches, normally open at the distant end, which are known as "bridged taps". We have found that these bridged taps if they are sufficiently long cause considerable irregularities in the transmission characteristics of the circuit, particularly in the high frequency range, due to reflection from the open ends. Consequently, in cases where the circuits are to be used as part of a transmission system employing a wide band of frequencies where a uniform transmission characteristic is desired, it becomes necessary to correct the irregularities caused by the bridged taps.

In accordance with the invention, smooth transmission between a transmitting terminal and a receiving terminal may be accomplished over a circuit, such as a subscriber's cable circuit in the telephone plant, to which are connected for purposes of flexibility a number of bridged circuits. A particular object of the invention is the provision of particular means whereby in such a transmission system smooth transmission characteristics may be obtained for energy passing from the transmitting terminal toward the receiving terminal.

A further object of the invention is the provision of an entire transmission system employing wire circuits each having at least one branch, capable of transmitting without undue distortion a wide band of frequencies.

While the invention will be defined in the appended claims, the features of the invention will be better understood from the detailed exposition which follows when read in connection with the accompanying diagrams, Figs. 1*a* to 6. Figure 1*a* represents a transmission circuit to which is connected a transmitting and receiving terminal and having connected to it at some point between them a bridged tap open at the far end. Fig. 1*b* and Fig. 1*c* when read in connection with Fig. 1*a* serve to assist in describing the effect caused by the bridged tap, while Fig. 2 shows for purposes of illustration a plot of the insertion loss and phase change due to a bridged tap connected across the circuit, said tap being open at the distant end, and Fig. 3 shows a plot of the insertion loss and phase change of a typical subscriber's loop having said bridged tap connected to it. Fig. 4 shows an arrangement for obtaining smooth transmission characteristics over the circuit indicated in Fig. 1*a* and Figs. 5 and 6 illustrate a system for the combined broadcasting of sound and television programs to a plurality of receiving points over a branching network including circuits to which are connected bridged taps.

Referring to Fig. 1*a*, transmission circuit 10 is a main circuit consisting of a pair of wires in a cable or some other electrical circuit. At one end of this circuit is a generator 11, having an internal impedance Z_G, which may be any source of energy to be transmitted to the distant receiver 12 having an impedance Z_R. At some point along this circuit, such as 13, is shown a branch circuit or bridged tap 14 consisting of a cable pair or other electrical circuit similar to the main circuit. This bridged tap is provided in order that the energy from the generator 11 may be utilized at an alternate location 15 if desired. In the system under discussion it is desired to utilize this energy at only one receiving station 12; hence this bridged tap is normally open at the end 15.

In order to determine the effect of the bridged tap on the transmission characteristics of the main circuit, reference is made to Figs. 1*b* and 1*c*. In Fig. 1*b* a generator 21 delivering a voltage E and having an internal impedance Z_G' has been substituted for the section of the line and associated apparatus to the left of the bridged tap in Fig. 1*a* and an impedance Z_R' has been substituted for the section of the line and the receiver Z_R to the right of the bridged tap. The bridged tap is omitted in this diagram. Now if the impedances Z_G and Z_R of Fig. 1*a* are made equal to the iterative impedance Z_o of the main circuit 10 of said figure, the impedances Z_G' and Z_R' of Fig. 1*b* will also be equal to Z_o. It may also be considered that the sections of the line 10 in either direction from the point 13, Fig. 1*a*, are electrically long. In this case an impedance equal to the iterative impedance of the circuit 10 in Fig. 1*a* may be substituted for the line sections on either side of the point 13. This is represented in Fig. 1*b* which represents the point 13 of Fig. 1*a* terminated on either side by the iterative impedance of line 10, Fig. 1*a*, or Z_o. The current which would then flow from the point 13 toward

the receiver 12 of Fig. 1*a* with no bridged tap connected to the circuit or in the impedance Z_R' of Fig. 1*b*, since Fig. 1*b* *is* equivalent to point 13 of the circuit 10 in Fig. 1*a* without the bridged tap, would be equal to

$$I_1=\frac{E}{Z_G'+Z_R'} \quad (1)$$

or, since $Z_G'=Z_R'=Z_o$,

$$I_1=\frac{E}{2Z_o} \quad (2)$$

In Fig. 1*c* the impedance of the bridged tap Z_S is shown shunted across the circuit between Z_G' and Z_R'. The impedances Z_G' and Z_R' and the generator voltage E are the same as those shown in Fig. 1*b*. For the condition indicated by Fig. 1*c* the current flowing in Z_R' is

$$I_2=\frac{E}{Z_G'+\frac{Z_SZ_R'}{Z_S+Z_R'}}\cdot\frac{Z_S}{Z_S+Z_R'} \quad (3)$$

or

$$I_2=\frac{EZ_S}{Z_G'Z_S+Z_G'Z_R'+Z_SZ_R'} \quad (4)$$

or

$$I_2=\frac{EZ_S}{Z_o^2+2Z_oZ_S} \quad (5)$$

which is the current which would flow from the point 13 toward the load 12 of Fig. 1*a* with the bridged tap connected across the circuit.

The ratio of the current at the point 13 which would flow toward the receiver 12 when the bridged tap is connected to the circuit 10 to the current which would flow toward receiver 12 with the bridged tap not connected is a measure of the insertion loss and phase change due to the bridged tap 14. From Equations (2) and (5) this ratio is

$$\frac{I_2}{I_1}=\frac{2Z_SZ_o}{Z_o^2+2Z_SZ_o} \quad (6)$$

It is well known that the impedance looking into a line, the other end of which is open, is equal to the iterative impedance of the line divided by the hyperbolic tangent of its image transfer constant (which is equal to the length of the line multiplied by its propagation constant per unit length), thus

$$Z_{oc}=Z/\tanh \gamma l \quad (7)$$

where Z_K is the iterative impedance, γ the propagation constant per unit length and l the length of the line. Equation (7) may be obtained directly from Equation (280), page 133, of "Principles of Electric Power Transmission and Distribution" by L. F. Woodruff. Now let it be assumed that the characteristic impedance and propagation constant of the bridged tap are equal to those of the main circuit. From Equation (7) the impedance of the bridged tap without the termination is:

$$Z_S=Z_o/\tanh \Gamma L \quad (8)$$

where Z_o is the characteristic impedance and Γ the propagation constant of both the bridged tap and the main transmission line and L is the length of the bridged tap. Substituting this value for Z_S in Equation 6 and simplifying, we obtain

$$I_2/I_1=\frac{1}{1+1/2\tanh \Gamma L} \quad (9)$$

This ratio is a measure of the insertion loss and phase change due to the bridged tap open at the far end when connected to the main circuit. To obtain the total insertion loss and phase change for the circuit shown in Fig. 1*a* connected between impedances equal to its iterative impedance, the insertion loss and phase change obtained from Equation (9) must be added to those for the line with the bridged tap omitted.

Examination of Equation (9) shows that both the insertion loss and phase change due to the bridged tap vary with the length of the tap and the frequency, since the propagation constant Γ is a function of frequency. In order to examine the nature of the variation of the insertion loss and phase change due to the bridged tap, since the mathematics involved become extremely complicated, it is simpler to show how this variation takes place for a specific case. If we take the case for which L is say, 800 feet or .15 mile and use values for Γ for a 24-gauge cable circuit and compute the current ratio I_2/I_1 from Equation (9), the results will be equal to those shown plotted in the curves of Fig. 2. The insertion loss here is expressed in db. and is indicated by the solid line and the phase change expressed in radians is shown as a dashed line. Computations have been made for frequencies up to 350 kilocycles.

To determine the total insertion loss and phase change for a circuit such as that shown in Fig. 1*a* where the bridged tap is .15 mile long, the insertion loss and phase change values shown in Fig. 2 must be added to those for the circuit without any bridged tap which, as is well known, would vary smoothly with frequency. It will, accordingly, be evident from Fig. 2 that the insertion loss and phase change for the overall circuit with bridged tap will be exceedingly irregular with frequency. This is illustrated in Fig. 3 in which the solid curves show a plot of the insertion loss and phase change versus frequency for a 24-gauge subscriber's loop 0.5 mile in length to which is connected the bridged tap described above.

In order to minimize the irregularities in the insertion loss and phase change, the arrangement shown in Fig. 4 may be employed in which an impedance equal to the iterative impedance of the bridged tap is shown connected to the distant end of the bridged tap. It has already been assumed that the characteristic impedance of the bridged tap is the same as that of the line so this terminating impedance may be designated as Z_o. The impedance looking into the tap where it is connected to the main transmission line will also be Z_o under this condition. Substituting this value for Zs in Equation (6) we obtain

$$\frac{I_2}{I_1}=2/3 \quad (10)$$

which holds regardless of the location of the bridged tap along the main circuit. The insertion loss due to the bridged tap is now a constant at all frequencies and the phase change due to the bridged tap is zero since the current ratio is a real number. Consequently, the insertion loss for the circuit with the terminated bridged tap included will be a smooth curve with values about 3.5 db. above the value of the insertion loss for the circuit with no bridged tap connected to it. The phase change for the circuit will not now be affected by the terminated bridged tap. This is illustrated by the dashed curves of Fig. 3.

In the above analysis the impedance of the bridged tap has been assumed the same as that of the main circuit. If the iterative impedance of the bridged tap is only approximately equal to that of the main transmission line, the treatment given above, while not strictly true, will be

substantially so and the distorting effects of the bridged tap on transmission will be corrected sufficiently for all practical purposes in substantially the same way as in the case given above.

The above discussion refers to a circuit with only one bridged tap. It may be shown in a similar manner that where there is more than one bridged tap, each terminated in its iterative impedance, the current ratio expressing the insertion loss and phase change due to the terminated bridged taps will be a constant real number independent of the frequency or length of the tap, so that the method for correcting irregularities in the transmission characteristics due to a single bridged tap will apply for those cases where more than one tap is involved.

It will be understood that although in the mathematical development in the disclosure, a specific value of impedance, namely the iterative impedance of the circuit, has been used for the terminating impedance for the tap, as well as for the impedance of the transmitter and receiver, it is possible to use other values of impedance without departing from the effectiveness of the invention.

The actual iterative impedances of cable circuits such as those commonly employed in the telephone plant are very nearly constant with frequency in the high frequency range and have small reactive components. Hence it is possible in this frequency range to use pure resistances for the transmitting and receiving impedances and for the terminating impedance for the bridged tap. Thus the insertion loss and phase change characteristics of the circuits may be smoothed out in the high frequency range where these characteristics are affected by the bridged taps in an extremely economical and simple manner by terminating each of the bridged taps in a pure resistance approximately equal in magnitude to the iterative impedance. Also at high frequencies the iterative impedances of the various gauges of cable circuits ordinarily encountered in practice are very closely the same so that the above theory holds substantially for main circuits and bridged taps composed of combinations of gauges of circuits which are ordinarily encountered in the telephone plant.

A possible application of the invention is in a one-way transmission system comprising a single transmitting terminal and a plurality of receiving terminals reached over a branching network, such as a local telephone network, which is made up of a number of trunk circuits to each of which are connected by suitable means a plurality of subscribers' circuits extending to receiving points, these subscribers' circuits having connected to them for purposes of flexibility a number of bridged circuits which are normally open at the distant end. In accordance with the invention, terminating impedances may be attached to the ends of these taps so that a smooth transmission characteristic may be obtained in such a network for energy passing from the transmitting terminal toward the receiving terminals.

Figs. 5 and 6 illustrate such a system in which a branching network including a considerable number of circuits of the type used in the local telephone plant, each having bridged taps, is utilized. In this case the network is incorporated in a system in which sound and television signals are transmitted from a single transmitting point over a number of trunk circuits to various central offices from which point the sound and television signals are transmitted over the subscribers' loops to a plurality of receiving points. Since the transmission characteristics of subscribers' cable circuits, particularly the attenuation and velocity of transmission, are more favorable for the transmission of television signals in the range above the voice frequency range, the television signals are stepped up in frequency and superimposed on the circuit at some frequency above the voice frequency range. This leaves the voice frequencies available for transmission of the sound program. Since by means of the method described above the insertion loss and phase change characteristics can be made to increase smoothly with frequency, equalization may be readily accomplished.

Referring to Fig. 5, at the point where the sound and television signals originate, there is located a television transmitting apparatus TT of any well known type, as, for example, that disclosed in a copending application of Frank Gray, Serial No. 227,649, filed October 21, 1927. This apparatus may include a suitable mechanism for scanning the image, photoelectric cells for converting the resulting light variations into electrical signals and means for amplifying these signals. The width of the band of signals obtained in the output of the television transmitter will depend upon the degree of image definition. In the present illustration it is assumed that this band extends from 0 to 100 kilocycles.

The television signals from the transmitter TT may be transmitted to a central distributing point over a trunk circuit PC_1 which may be an ordinary cable pair or other suitable circuit. At the distributing center, the television signal band is first applied to a modulator TM_1 which is supplied by an oscillator TC_1 with a carrier frequency assumed to be 400 kilocycles. In the output of this modulator the upper and lower side bands of modulation, namely, 300–400 kilocycles and 400–500 kilocycles, together with the carrier frequency, are selected by the filter TF_1 which suppresses other unwanted modulation products and the input frequencies. The output of this filter is applied to a second modulator TM_2 which is provided by the oscillator TC_2 with a carrier frequency assumed to be 250 kilocycles. In the output of this modulator, the lower side band components present, the two television sidebands extending from 50 to 250 kilocycles, and a carrier frequency of 150 kilocycles are selected by the filter TF_2 which excludes the undesired frequencies. The output of this filter is passed through the amplifier TA_1 and transmitted over a trunk circuit PC_2 to an intermediate amplifier TA_2 which may be located at a telephone central office. Here the signals, after passing through the amplifier TA_2, are passed through the impedance step-down transformer TR_1 to a common bus PB_1 to which are connected grouping buses PB_2. The grouping buses PB_2 are connected to the main bus PB_1 through protective resistances PR_1 the purpose of these resistances being to limit the transmission loss for other groups due to a short circuit occurring in any one group. The subscribers' circuits are in turn connected in groups to the grouping bus, each subscriber's circuit being connected through protective resistances PR_2.

The sound signals accompanying the television signals are picked up and amplified in the apparatus ST at the transmitting point. These signals may extend from about 30 cycles to 10,000 cycles. The signals are then transmitted over a trunk circuit PC_3 to the central distributing point

where, after passing through the amplifier SA_1 and filter SF_1, they are transmitted over the trunk circuit PC_4 to the intermediate point where they are amplified in the sound amplifier SA_2 and combined with the television signals for application to the subscribers' circuits.

The subscribers' circuits PC_{10}, PC_{11}, etc., may consist of a plurality of cable circuits similar to subscribers' telephone loops, each loop having one or more bridged taps connected to it. At the distant end of each of these taps is connected a resistance R approximating the iterative impedance of the tap circuit.

At any one receiving point such as that illustrated in Fig. 6, the television signals from the line PC_{10} may be selected by the filter TF_3 and applied to the modulator TM_3 which is supplied with a carrier frequency of 250 kilocycles from oscillator TC_3. In the output of this modulator the twin sidebands extending from 300 to 500 kilocycles, accompanied by a carrier frequency of 400 kilocycles, are selected by the filter TF_4. The original television band is then obtained through the demodulator TM_4 with a filter TF_5 for the purpose of eliminating undesired frequencies in the output. The signals are then applied to a television receiver TR which reproduces the original image. This receiver may be of any suitable type, such as, for example, that described in the application of Gray previously referred to.

The sound signals are selected at the receiving point by the filter SF_2, amplified by the amplifier SA_3 and applied to the loud speaker LS.

If it is desired to have more than one program at the receiving point, additional transmitting apparatus and distributing networks may be provided while the receiving apparatus may be arranged to be set to any desired program by means of a switching arrangement, shown in Fig. 6, so arranged that when the sound and television apparatus is not connected to an incoming subscriber's loop, its branch is terminated in a resistance R approximating the iterative impedance of the loop. The input impedance of a receiver is, of course, arranged to be approximately equal to the characteristic impedance of the line.

While the invention has been disclosed for purposes of illustration in certain specific forms, it will be obvious that its basic principles as defined in the appended claims are such as to permit its incorporation in many widely different arrangements.

What is claimed is:

1. In a system for the distribution of sound and television programs, transmitting apparatus, a network of main circuits extending from said transmitting apparatus to a plurality of receiving points each of said circuits having at least one additional circuit connected thereto, means connected across the distant end of the said additional circuit for avoiding the reflection of energy due to each additional circuit over a wide range of frequencies, the aforesaid means being equal to the iterative impedance of the said additional circuit and translating means at said receiving points for utilizing sound and television signals.

2. In an electrical transmission system, a network of circuits extending from a single transmitting point to a plurality of intermediate amplifying points, and from each amplifying point a network of circuits each of said latter circuits having connected thereto at least one branch circuit, said network being designed for the one-way transmission of a band of frequencies capable of providing simultaneously a high quality sound program and a television program having a high degree of image definition, means for avoiding the reflection of energy due to each of said branch circuits, said means consisting in a terminating impedance approximately equal to the iterative impedance of each branch circuit connected to the distant end of each branch circuit, means at said transmitting point for applying sound and television signals to said network and means at said receiving points for receiving and utilizing said signals.

3. In a system for the distribution of sound and television programs, transmitting apparatus, a main circuit extending from the said transmitting apparatus to a receiving point, the said circuit having an additional circuit connected thereto, means connected across the distant end of the said additional circuit for avoiding the reflection of energy due to the additional circuit over a wide range of frequencies, the aforesaid means being equal to the iterative impedance of the said additional circuit, and translating means at the said receiving point for utilizing sound and television signals.

4. In a system for the distribution of sound and television programs, the combination with transmitting apparatus of a main circuit extending from the said transmitting apparatus to a receiving point, the said circuit having an additional circuit connected thereto, an impedance network connected across said additional circuit at its distant end, the said network being approximately equal to the iterative impedance of the said additional circuit, and translating means connected to the main circuit at the said receiving point for utilizing the said sound and television signals.

5. In a system for the distribution of sound and television programs, the combination with television transmitting apparatus having a transmitting circuit extending therefrom of sound transmitting apparatus also having a transmitting circuit extending therefrom, a common circuit to which both of said transmitting circuits are connected, a plurality of subscribers' circuits connected to the said common circuit each of said subscriber's circuits having an additional circuit bridged across it and each additional circuit being terminated in an impedance substantially equal to the iterative impedance of the respective additional circuit, and means connected to each subscriber's circuit to reproduce the said sound and television programs.

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