Jan. 14, 1930. E. I. GREEN 1,743,132

EQUALIZATION OF CARRIER SYSTEMS

Filed Jan. 28, 1928 4 Sheets-Sheet 1

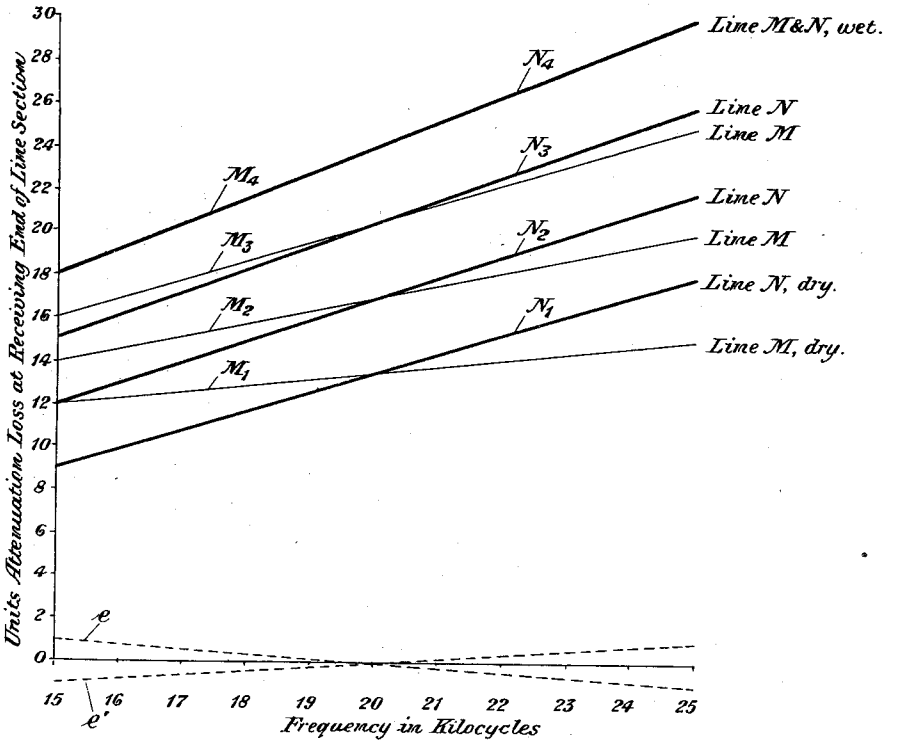


Fig. 1

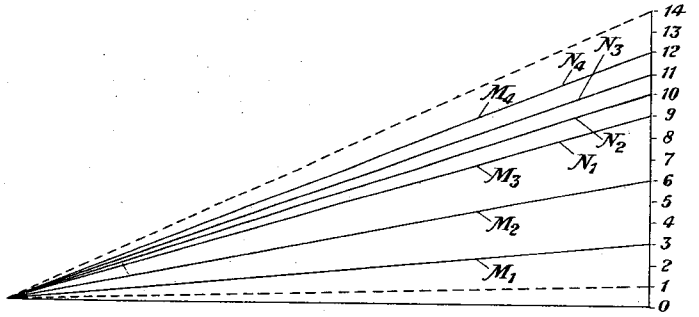


Fig. 2

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EQUALIZATION OF CARRIER SYSTEMS

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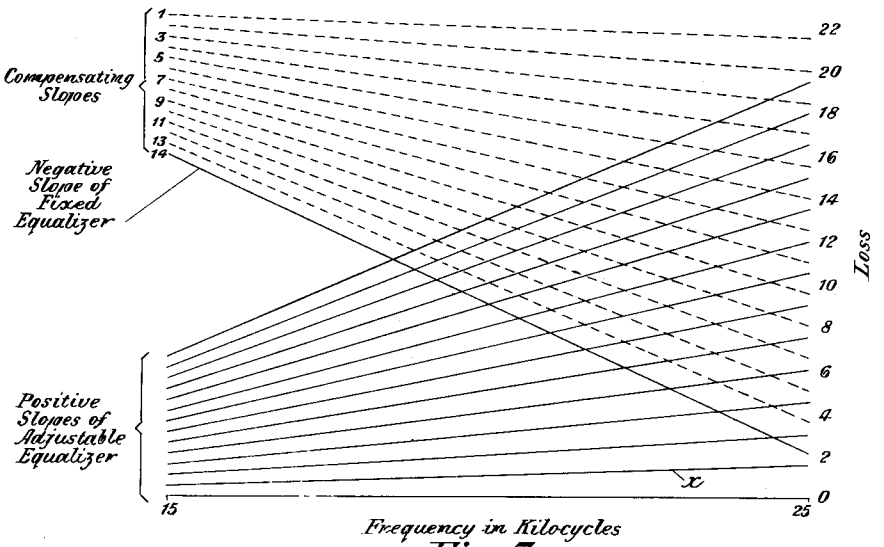


Fig. 3

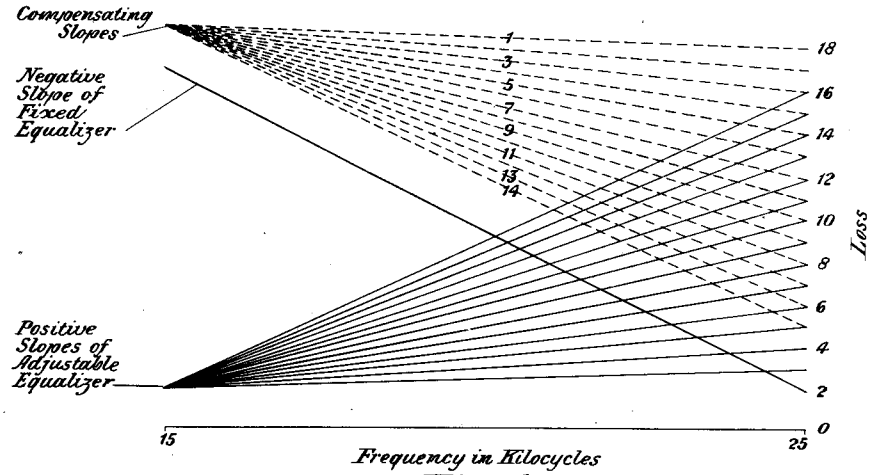


Fig. 4

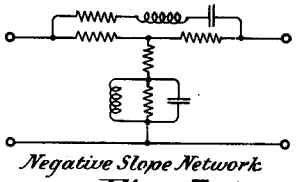


Fig. 5

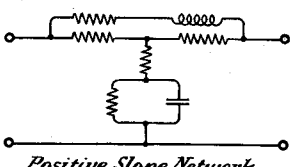


Fig. 6

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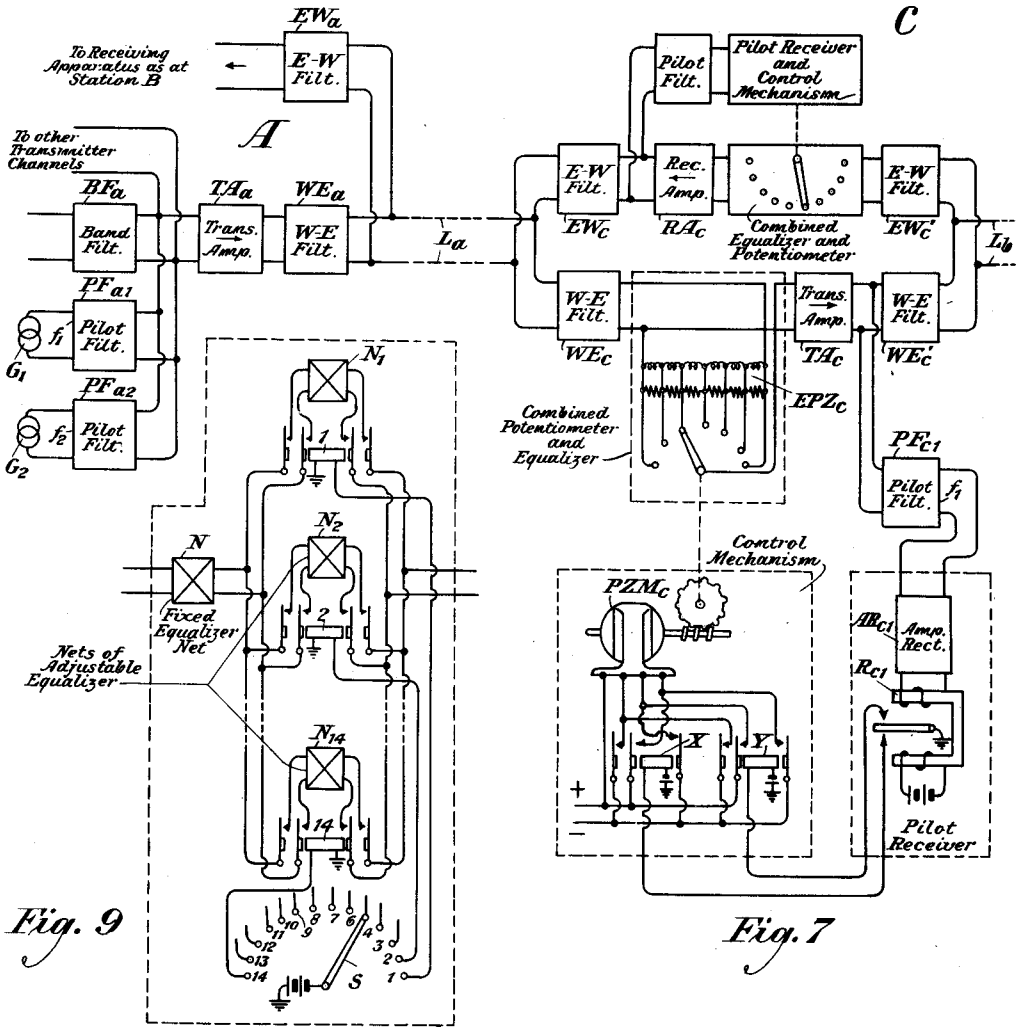


Fig. 9

Fig. 7

Fig. 8

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EQUALIZATION OF CARRIER SYSTEMS

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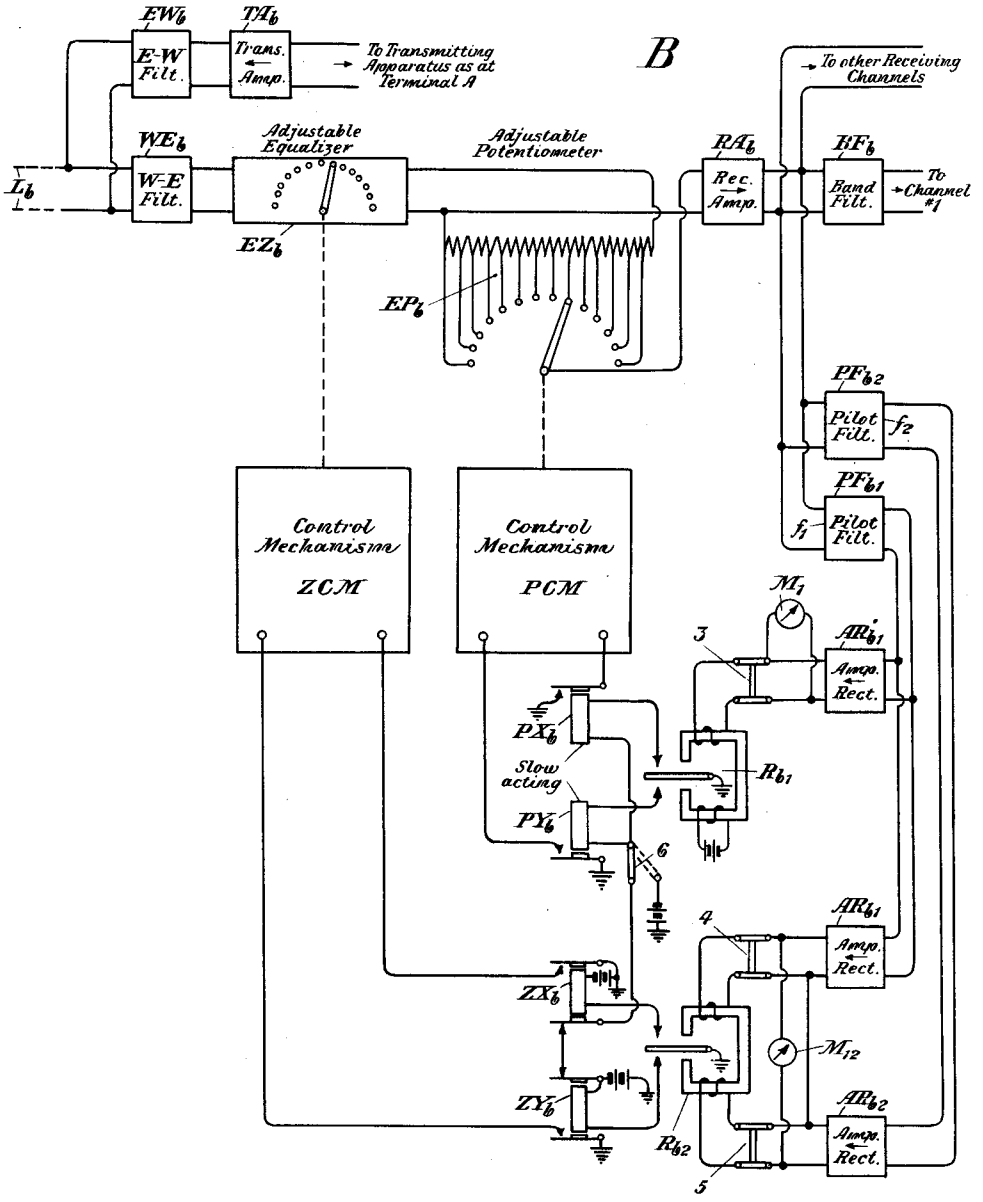


Fig. 7a

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Patented Jan. 14, 1930

1,743,132

UNITED STATES PATENT OFFICE

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EQUALIZATION OF CARRIER SYSTEMS

Application filed January 28, 1928. Serial No. 250,210.

This invention relates to the equalization of carrier systems so that all of the channels will be brought to substantially a common transmission level, the common level may be maintained constant with changes in transmission conditions.

In a transmission system employing line conductors, the attenuation of the current varies with frequency, the attenuation increasing as the frequency goes up. This becomes a very serious matter in a multiplex carrier system as the channels having the higher carrier frequencies will be much more attenuated than the channels transmitting at lower carrier frequencies. If, in such a system, the attenuation is plotted against frequency, the resultant curve will, within reasonable frequency limits, approximate a straight line having a slope depending upon the character of the circuit and the existing transmission conditions. This slope varies with different transmission conditions, and the variation in slope will, moreover, be different for different types of circuits.

Obviously, it is desirable that some form of compensation be made so that the transmission at a given frequency be maintained at a desired level, and that some further compensation be made to bring all channels at all times to that level. In other words, some compensation should be made so that the resultant slope will be horizontal, and will be maintained horizontal at a desired transmission level.

In the case of a carrier telephone system, the term transmission level is generally understood to signify, not the absolute power in a particular frequency band, but the relation between the power transmitted past any point in the system and the power at some arbitrary reference point, usually at the transmitting end of the system.

Heretofore it has been proposed to accomplish these results by transmitting a pilot frequency over the circuit, observing the level of the pilot frequency at one or more stations (usually at each repeater station and at the receiving terminal), adjusting a potentiometer which treats all frequencies alike to compensate for the observed change in level at the pilot frequency, and at the same time making a level equalizing adjustment of some network in the circuit to compensate for the slope of the attenuation frequency characteristic assumed to exist at the particular pilot frequency amplitude observed.

Unfortunately, lines constructed with different gauges of wire and different types of insulators give different changes in slope for a given change in the over-all transmission equivalent. Furthermore, changes may occur in the gain of the repeaters due to variations in the battery supply, and as these changes in gain produce no change whatever in the attenuation frequency slope, it is evident that an adjustment of a potentiometer over a certain number of steps to bring the transmission level back to normal, accompanied by a compensating slope adjustment for each step, will not necessarily result in a compensating slope corresponding to the particular slope of the attenuation-frequency characteristic of the line existing at the time the received current was measured. In short, an identical change of slope on two different types of circuits may be accompanied by a different change in loss on the two circuits, and under certain circumstances an identical change of slope on a given circuit may be accompanied by different changes in loss at the same frequency at different times. Such a condition obviously makes the control of the equalizing slope according to changes in the over-all attenuation observed at a single frequency more or less unsatisfactory.

Accordingly, it is proposed, by means of the present invention, to so arrange matters that the equalization or slope correction be controlled by means of two pilot frequencies transmitted over the system, one or both of these frequencies serving also to control the adjustment of a potentiometer or other device for bringing the circuit back to a normal transmission equivalent. By transmitting two pilot frequencies and observing the difference in the amplitudes at which they are received, the attenuation frequency slope is determined. Suitable adjustments may be then made in an equalizer or slope correcter to bring the over-all frequency attenuation

curve for the system, including the equalizer, to a common horizontal level. This adjustment may be made either manually or automatically. An independent adjustment of the gain of an amplifier may then be made by means of a potentiometer or equivalent device to change the gain equally at all frequencies to such an extent as to bring the now common level of the circuit up to the normal level. By this method of compensation the same equalizing and level adjusting apparatus may be used for all circuits in the plant, regardless of their character, and the adjustments will approximate an ideal condition under various conditions of any given circuit.

The invention will now be more fully understood from the following detailed description when read in connection with the accompanying drawing in which Figure 1 shows a series of curves illustrating the attenuation-frequency characteristics of two different circuits under variable weather conditions; Fig. 2 shows a series of curves illustrating the changes in slope corresponding to the various conditions illustrated in Fig. 1; Fig. 3 shows a series of curves illustrating how compensating slope adjustments may be made by using a fixed equalizer network having a negative slope in combination with various networks having positive slopes which may be built up to obtain the desired compensating slope; Fig. 4 shows a similar set of curves in which the slopes of the compensating networks all pass through a common level at one of the pilot frequencies so that that particular pilot frequency may be used to control the gain adjustment independently of the level compensating or equalizing adjustment; Figs. 5 and 6 illustrate types of networks which may be used for obtaining desired negative and positive slopes for various equalizer adjustments; Figs. 7 and 7ª taken together illustrate a circuit arrangement for carrying out the principles of the invention; while Figs. 8 and 9 illustrate two different forms of adjustable equalizers which may be used in connection with the invention.

Referring to Fig. 1, let us suppose we have a transmission line which we will call M, and that we transmit over this line a range of frequencies each having the same level at the transmitting end. If we measure the received current at the several frequencies under dry weather conditions, it will be found that the attenuation loss with frequency will progressively increase, as shown by the curve M_1 of Fig. 1. Under wet weather conditions, the attenuation will be greater at all frequencies, but the increase in attenuation will be greater for the higher frequencies, as indicated by the curve M_4 of Fig. 1. The curves M_1 and M_4 have different slopes, and at intermediate conditions between wet and dry, the same circuit may have the attenuation curves indicated at M_2 and M_3 of Fig. 1, each of these curves having still different slopes.

Now, if we observe the transmission loss for some particular frequency at a given instant, it is possible to adjust a potentiometer and increase the gain to bring the transmission level at that frequency up to the level at which it started, or to any other level that may be desired. If, furthermore, the construction of the line remains unaltered and no changes occur in the repeaters due to battery fluctuations, or the like, it will be possible to associate with each step of adjustment of the potentiometer a corresponding step in the adjustment of a network or combination of networks by means of which the proper compensating changes will be made for the other frequencies involved, so that all frequencies will be adjusted to the same level. In other words, a network may be cut into the circuit each time a compensating change is made in the gain of a repeater, which network will have an attenuation frequency characteristic whose slope will be just the reverse of that of the line, so that the combined slope of the network and the line will be horizontal. This involves the assumption that the slope adjustment corresponding to each setting of the potentiometer is known in advance. A system involving this principle is disclosed in Affel Patent No. 1,511,013, of October 7, 1924.

Suppose, now, we have another transmission line which we will call N having attenuation frequency characteristics, as indicated at N_1, N_2, N_3 and N_4 of Fig. 1. If we assume that the pilot frequency, whose loss is measured in order to determine the potentiometer and other adjustments, be 20 kilocycles, for example, it will be evident that while the attenuation measurements will enable us to adjust a potentiometer to control the level at that particular frequency, the corresponding slope compensating networks which were used in the case of line M will not fit the present case at all. In fact, an inspection of the curves at Fig. 1 shows that a knowledge of the transmission loss at 20,000 cycles, for example, gives us no information whatever as to the slope compensation which should be made, as the slope will vary from that of the curve M_1 to that of the curve N_1 even under the same transmission conditions.

Furthermore, let us suppose we are measuring the loss at 20 kilocycles over the line N under dry weather conditions, and that due to some abnormal condition of one or more repeaters, (which change the gain at all frequencies alike), we get a measured attenuation loss of 20½ units instead of 12½ units. The observer will then, knowing he is working with the line N, assume that he should make a slope compensating adjustment corresponding to the curve N_3 of Fig. 1. Now, the facts are that under these conditions the

slope would be the dry weather slope represented by curve N_1, the only difference due to the repeater being that the loss at all the frequencies involved would be increased eight units, so that the actual attenuation frequency curve for this particular condition would be as represented by the curve M_3 of Fig. 1. (The curve M_3, while drawn for the line M, is parallel to the curve N_1 and happens to accurately represent the assumed abnormal condition on the line N_1). Obviously, if we make a slope adjustment corresponding to N_3, it will be incorrect as the slope adjustment should correspond to M_3 (or N_1).

It is therefore clear that measurements of the attenuation loss at one frequency will not afford sufficient data from which to determine both the necessary potentiometer adjustment and the necessary slope compensating adjustment. Therefore, in accordance with the present invention, it is proposed to make measurements of the attenuation loss of the circuit at two frequencies. This will give data from which we will know at any time the slope of the attenuation frequency curve and the actual attenuation loss at each frequency over the range with which we are concerned,—this, regardless of the nature or character of the circuit over which the measurements are made, and regardless of changes either in the character of the individual elements of the system or in the external conditions which affect the transmission of the circuit.

For example, if in Fig. 1 we use 15 kilocycles and 25 kilocycles as the pilot frequencies and measure the attenuation loss at each of those frequencies, such attenuation measurements fix at once the slope of the attenuation frequency curve for the circuit at that time. If we make measurements at these two frequencies and find that at 15 kilocycles the loss is 9 units, and at 25 kilocycles the loss is 18 units, we know the slope for which compensation must be made is that represented by the line N_1. If, one the other hand, the observed attenuation losses are 16 units and 25 units, respectively, we know that the slope for which compensation must be made is that of the curve M_3, which, as it happens, is the same as that of the curve N_1. It is unnecessary to learn anything about the nature of the line over which the measurements are being made, or anything about the weather conditions. The two measurements fix the slope of the curve absolutely.

Having made the necessary slope compensating adjustment so that now all frequencies are received at the same level, such level may be shifted up and down by means of a potentiometer to bring it to any desired level at which the transmission equivalent of the circuit is to be maintained. Such potentiometer adjustments, or changes in gain of amplifiers, produce no change in the slope of the over-all attenuation frequency characteristic of the circuit. Consequently, the slope or equalization adjustments may be made quite independently of the over-all transmission level adjustment.

The various slopes represented by the curves M_1, M_2, etc., and N_1, N_2, etc., of Fig. 1 are shown in their relationship to each other in Fig. 2, where each of the curves is drawn with the same slope as in Fig. 1, but through a common point of origin. The curves of Fig. 2 show that for the two circuits M and N there are two slopes for each circuit which are the same. For example, curves M_4 and N_4, representing wet weather conditions of the two lines, have the same slope. Also, it happens that the curve N_1, representing the dry weather condition of the line N, has the same slope as the curve M_3 of the line M. Therefore, so far as bringing all of the channels to the same level is concerned, it will be necessary to have adjustable networks capable of producing compensating slopes corresponding to those slopes numbered 3, 6, 9, 10, 11 and 12 of Fig. 2 in order to take care of the several conditions illustrated in Fig. 1 for the two lines M and N.

Assuming that the compensating arrangements are to correct for intermediate weather conditions not indicated in Fig. 1, or that they are to be used with still other lines having different characteristics, it might be desirable to have compensating adjustments varying by frequent steps all the way from slope 1 to slope 14 of Fig. 2.

A convenient way to attain the desired range of slope adjustments would be to have a fixed network or equalizer to compensate for the slope under the worst conditions which could be met with in practice, and supplement this network by a number of other networks giving opposite slopes. Assuming that the slope 14 of Fig. 2 represents the worst condition that will have to be met, the fixed equalizer or network could then have the attenuation frequency characteristic illustrated by the curve 14 of Fig. 3. This curve, it will be seen, has a negative slope which corresponds exactly to positive slope 14 of Fig. 2. The various other slopes may then be obtained by means of a set of equal networks whose attenuation characteristic may be that represented at x in Fig. 3. This curve, it will be noted, has a positive slope, and, by combining in tandem any number of such equal networks, we will obtain the various positive slopes for the adjustable equalizer indicated in Fig. 3. By superposing the loss represented by these various positive slope networks upon the loss represented by the fixed equalizer and network, the several slopes from 13 to 1, inclusive, represented in dotted lines in Fig. 3, may be obtained. It will be noted that the various negative compensating slopes from 1 to 14, inclusive, of Fig. 3, correspond

to and will compensate for the various compensating slopes from 1 to 14, inclusive, in Fig. 2.

The number of positive slope networks which it is necessary to employ may be reduced by providing several networks of such slopes that their addition in various combinations will produce all the desired slopes. Thus, for example, four positive slope networks as designated by losses of 2, 4, 8 and 16 units in Fig. 3 could be combined in different ways to give all of the positive slopes indicated in the figure.

The advantage of the arrangement of Fig. 3 which uses only one network having a negative slope and obtains the other desired slope steps by means of a corresponding number of networks each having positive slopes, is considerable. A typical network capable of giving a negative slope is illustrated in Fig. 5, while a network capable of giving a positive slope, such as that of x in Fig. 3, is illustrated in Fig. 6. Not only is the network of Fig. 6 (which has the positive slope) simpler and cheaper than that of Fig. 5, due to the fact that it uses fewer elements, but it also happens that the mathematical design of a network of the type of Fig. 6 is considerably simpler than the design of a network such as that of Fig. 5, giving a negative slope. The characteristics of networks of these two types are discussed at length in the patent to Zobel, No. 1,603,305, of October 19, 1926.

In the foregoing discussion, it has been assumed that the attenuation-frequency curves are straight lines, as indicated in Fig. 1. While this is approximately true over the limited range of frequencies employed for all of the channels of a carrier system transmitting in one direction, in actual practice there is a slight curvature in these lines over the entire useful frequency range. This does not introduce any material complication, however, as the curves all have the same general form, and the networks making up the adjustable equalizer can be designed, and in practice are designed, to take care of the slight amount of departure from the straight line involved at each slope for which compensation is to be made.

Figs. 7 and 7ª when placed side by side, illustrate schematically a circuit arrangement for carrying out the invention. The two terminal stations A and B are shown with an intermediate repeater at station C, the repeater being connected with the terminal stations by line sections L_a and L_b, respectively. It will be understood, of course, that in practice any desired number of intermediate repeater stations will be provided.

At station A, the various carrier transmitting channels are combined through band filters such as BF_a, (only one of which is shown), in a transmitting amplifier TA_a, the various frequencies used for transmitting then passing through a directional filter WE_a to the line. The receiving channels are branched from the line through a similar directional filter EW_a. The pilot apparatus at station A comprises two generators G_1 and G_2 for producing the pilot frequencies f_1 and f_2 which may be passed through pilot filters or selecting devices PF_{a1} and PF_{a2}, respectively, these pilot frequencies then passing to the line though the transmitting amplifier and directional filter which carry the carrier channels. Only the transmitting apparatus is shown at station A.

At station B, the corresponding receiving apparatus is illustrated. Here the carrier channels pass through directional filters WE_b to a common receiving amplifier RA_b, from the output of which the carrier channels are separated into their respective terminal circuits through band filters such as BF_b, only one of which is illustrated. The gain of the amplifier RA_b is controlled by means of an adjustable potentiometer EP_b, as will be described later. An adjustable equalizer EZ_b for compensating for the slope of the attenuation-frequency characteristic of the received range of frequencies is also interposed in the circuit. The nature and operation of these devices will be discribed in more detail later. The transmitting apparatus at station B is not illustrated, it being understood that this apparatus will be similar to that at station A, and that the various channels (including pilot frequencies for transmission in the reverse direction) are combined in the common transmitting amplifier TA_b and pass to the line through the directional filter EW_b.

At the repeater station, the two line sections L_a and L_b are connected by two paths, one for transmitting in each direction. The east-west path selects all the channel frequencies transmitted in that direction by means of the filters EW_c and EW'_c. Similarly, the west-east path selects all of the channel frequencies transmitting in the opposite direction by means of the filters WE_c and WE'_c. A transmitting amplifier TA_c is included in the west-east path for amplifying all frequencies transmitting in that direction, the gain of this amplifier being controlled by means of a combined potentiometer and equalizer EPZ_c which may be of the type disclosed in the patent to Affel, above referred to. Simliarly, the east-west path of the repeater includes a common amplifier RA_c controlled by a similarly combined equalizer and potentiometer indicated symbolically.

In accordance with the arrangement illustrated, it is assumed that the transmission level at one pilot frequency will be maintained constant in the manner disclosed in the Affel patent above referred to, and that an approximate compensation for the slope of the attenuation frequency curve will be

made by the equalizing arrangement which is combined with the potentiometer, a more exact compensation for the slope being obtained at the receiving terminal by means which will be described later.

In order to adjust the combined potentiometer and equalizer EPZ_c, one of the pilot frequencies, say f_1, is selected at the repeater station by means of the filter PF_{c1} and is transmitted to an amplifier-rectifier AR_{c1} to produce a direct current proportional to the amplitude of the received pilot frequency. This current operates a relay R_{c1}.

When the transmission conditions are normal at the pilot frequency, the armature of the relay R_{c1} is adjusted so that it will be in a neutral position. If, however, the transmission level departs from normal, due to change in weather conditions, or what not, the armature will be shifted to one or the other of its back contacts, depending on whether there is an increase or decrease in the received current. This operates either the relay X or the relay Y of Fig. 7 to operate the motor PZM_c in either a forward or a reverse direction, depending upon which way the armature of the relay is actuated. This motor may be mechanically arranged to set the switch of the potentiometer EP_c to any desired position. The switch is therefore shifted until the gain of the amplifier is increased or reduced to such point that the received pilot frequency is restored to its normal amplitude. The potentiometer consisting of simple resistance steps produces the same change in gain at all of the carrier frequencies involved. In order to approximately compensate for the differences in level of the different channels, or, in other words, in order to compensate for the slope of the attenuation-frequency characteristic, slope compensating inductances are connected in parallel with the resistance elements of the potentiometer, so that for each setting of the potentiometer there will be a corresponding setting for slope compensation. This will give an approximate slope compensation subject, of course, to the necessary errors previously pointed out. The principles underlying the apparatus at the repeater station C are fully described in the Affel patent above referred to.

By providing additional switch points on the steps of the potentiometer more complicated forms of equalizing networks, similar to those employed at the receiving terminal, may be used instead of the inductances mentioned above. As in the case of the inductances, one equalizing slope is to be used with each potentiometer setting.

It will be understood, of course, that a similarly controlled mechanism will be associated with the east-west path of the repeater at station C to make adjustments for controlling transmission in the opposite direction. It will also be understood that, if desired, the combined potentiometer and equalizer EPZ_c may be operated by hand in response to observed variations in the direct current in the output circuit of the amplifier-rectifier AR_{c1}.

The apparatus at the repeater station C, involving, as it does, the use of only one pilot frequency, can only approximate the necessary correction for the slope of the attenuation frequency characteristic. The various channels transmitted over the line section L_b to the station B will be attenuated in accordance with their frequencies, so that the apparatus at station B must compensate for the slope due to transmission over the line section L_b, which may take some one of the forms indicated in Fig. 1, and to this slope will be added a change in slope due to the combined deviation from true correction at the various repeater stations. This deviation may be assumed to vary between the limits represented by the curves e and e' of Fig. 1. This additional variation of attenuation with frequency must be taken care of by the compensating arrangement illustrated in Fig. 7[a] at station B, now about to be described.

In order to compensate for the slope of the effective attenuation-frequency curve for the entire system, as it appears at station B and at the same time control the magnitude of the currents in the different carrier channels, the received pilot frequencies f_1 and f_2 are selected from the output of the common amplifier RA_b by means of filters PF_{b1} and PF_{b2}. The frequency f_1 is applied to an amplifier-rectifier unit AR_{b1} to produce a direct current proportional to the amplitude of the frequency f_1 as received. Any departure from the normal magnitude of this direct current operates a receiving relay R_{b1} which controls a controlling mechanism PCM for the adjustable potentiometer, as will be described later.

In order to similarly operate the control mechanism ZCM for the adjustable equalizer, the frequencies f_1 and f_2 are separately impressed upon amplifier-rectifier units AR_{b1} and AR_{b2}, respectively. The rectified direct currents from these amplifier-rectifier units are combined, in opposing relation, upon the windings of relay R_{b2} to actuate the control mechanism ZCM. The pull upon the armature of this relay will be proportional to the difference between the magnitudes of the two pilot frequencies as received. The pull upon the armature will therefore be a measure of the slope of the attenuation-frequency curve for the over-all circuit and will be independent of the absolute amplitudes of the two pilot frequencies.

The control mechanisms ZCM and PCM will, of course, be in all respects similar to the control mechanism illustrated in Fig. 7. It is to be understood, however, that the control mechanism illustrated in Fig. 7 represents

only one of a large number of devices, well known in the art, which might be utilized for accomplishing the desired result, and the invention is not therefore to be understood as limited to any particular type of control mechanism.

Where the adjustable equalizer EZ_b is to function in accordance with the principles discussed in connection with Fig. 3, such equalizer may be made up as illustrated in Fig. 8. Here, a switch S may be adjusted to any one of a number of contact positions, the number of contact positions being, for purposes of illustration, shown as comprising fourteen. Each of these contact positions corresponds to one of the curves 1 to 14, inclusive, of Fig. 3. A fixed equalizing network N_{14}, which may be of the type shown in Fig. 5, is provided, this network having the characteristics indicated at curve 14 of Fig. 3. Individual networks N_1 to N_{13} are provided, these networks being of identical construction and having positive slopes, as indicated by the characteristic curve x of Fig. 3. These networks may be of the type illustrated in Fig. 6.

Switching relays 1 to 14, inclusive, are associated with the contacts 1 to 14 of the controlling switch for the purpose of switching the networks into the line circuits in any desired combination. The relay contacts are so arranged that with none of the relays energized, all of the networks N_1 to N_{14}, inclusive, are connected in tandem over the back contacts of the relays. The fixed equalizer network N_{14} is permanently connected to the line terminals at the left. When any relay is operated, all of the networks to the left thereof are disconnected from the networks to the right and are connected directly over the front contacts of the relay to the line terminals at the right.

For example, if it is desired to compensate for the slope indicated at 14 in Fig. 2, the switch S will be moved to position 14, thereby energizing the relay 14 which disconnects network N_{14} from all the remaining networks and connects said network N_{14} directly to the line terminals at the right. If the switch is moved to position 13, relay 14 is deenergized and relay 13 is energized. This results in disconnecting network N_{13} from the networks to the right thereof and connecting it directly to the line terminals at the right. Network N_{13} is, of course, connected in tandem with network N_{14} by the release of relay 14. This combination will compensate for the slope shown at 2 in Fig. 2. If the switch is moved to position 2, relay 2 is actuated. All of the relays to the left of relay 2 being deenergized, all of the networks N_2 to N_{14}, inclusive, are connected in tandem. The relay 2 disconnects these networks from network N_1 and connects them directly to the line terminals at the right. This gives a combination which will compensate for a slope corresponding to 2 of Fig. 2.

The switch S of Fig. 8 may be, of course, operated by the control mechanism ZCM under the control of the relay R_{b2} of Fig. 7[a]. Since the adjustment of the equalizer introduces increased loss in the circuit at the pilot frequency, as will be clear from the curves of Fig. 3, it is desirable that the adjustment of the equalizer EZ_b take place before any adjustment of the potentiometer EP_b is made. Accordingly, the relay R_{b2}, which determines the slope compensation, is arranged so that it does not control the control mechanism ZCM directly, but controls said mechanism through relays ZX_b and ZY_b. Therefore, if at any time the slope of the circuit is abnormal, that is, not horizontal, there will be a difference in the output currents of the two amplifier-rectifier units AR_{b1} and AR_{b2}, so that the relay R_{b2} will operate one or the other of the relays ZX_b or ZY_b. The operation of either of these relays disconnects battery from relays PX_b and PY_b through which the pilot receiving relay R_{b1} operates the control mechanism PCM for the adjustable potentiometer EP_b. This prevents any adjustment of the potentiometer while the control mechanism ZCM is adjusting the equalizer EZ_b to bring all of the channels to the same level. When the channels have all been restored to the same level, the armature of the relay R_{b2} will return to its neutral position, thereby releasing the relay ZX_b or ZY_b, as the case may be. As the level at the pilot frequency f_1 will now be abnormal, the relay RB_1 will be unbalanced and its armature will close the circuit of one of the relays PX_b or PY_b to operate the control mechanism PCM which in turn adjusts the potentiometer EP_b to bring the level up to normal.

It is therefore clear that so long as all the channels are at the same level, there will be no response upon the part of the relay R_{b2} and any change in the amplitude of the pilot frequency f_1, which may occur without any corcoresponding change of slope, will be compensated for by the action of the relay R_{b1} to adjust the potentiometer EP_b. If, however, there is a change in the pilot frequency f_1 with some corresponding change in slope, the slope compensating mechanism will come into operation first and will restore the circuit to a horizontal slope, after which the potentiometer adjusting mechanism will come into play to restore the level of all the channels to normal.

It will be understood, of course, that the operation need not be automatic, as above described. Instead, if the switches 3, 4 and 5 are opened to disconnect the receiving relays R_{b1} and R_{b2}, the pilot reading at frequency f_1 may be noted on meter M_1, and the difference between the amplitudes of the pilot frequencies f_1 and f_2 may be noted on the meter M_{12}.

The attendant may then manually adjust the dial switches of the equalizer EZ_b and the potentiometer EP_b to compensate for the abnormal slope indicated and to restore the level to normal.

In some instances, it might be advantageous if the equalizer adjustment and the potentiometer adjustment could take place simultaneously and independently of each other. This is possible where all of the compensating slopes pass through a common point at the pilot frequency which is used to control the potentiometer. For example, in Fig. 4, fourteen curves are shown in dotted lines, which will compensate for the slopes 1 to 14 of Fig. 2. All of these curves pass through a common loss value of 19 units at the lower frequency of the two pilot frequencies, which is here assumed to be 15 kilocycles. These curves 1 to 14 may be made up by a fixed equalizer whose curve will have a negative slope to which may be added any one of fourteen individual networks having the compensating slopes indicated in full lines in Fig. 4. This will involve an individual network with a compensating slope for each of the full line curves. Accordingly, the adjustable equalizer EZ_b in this case will be arranged as in Fig. 9 so that any desirable adjustment may be made. The fixed equalizer having the negative slope will be connected in tandem at any one time with one only of the fourteen networks having positive slopes. As will be clear from Fig. 9, the adjustment of the switch S to any contact point, as, for example, contact point 2, will energize the corresponding relay 2 which in turn interpolates a network N_2 having a positive slope between the fixed equalizer net N having a negative slope and the line terminals at the right. If the switch is on contact 1, relay 1 replaces network N_2 by the network N_1; and if the switch is on point 14, relay 14 substitutes network N_{14} for the other network having the positive slope. In this manner, any one of the adjustments indicated in dotted lines in Fig. 4 may be obtained.

While this arrangement has the disadvantage that each one of the networks N_1 to N_{14}, inclusive, will have to be separately designed, it has the obvious advantage that any adjustment of the slope is without effect upon the transmission equivalent at the pilot frequency which controls the potentiometer. If the circuit is to be operated in this manner, the switch 6 of Fig. 7[a] will be shifted to its dotted line position, thereby removing relays PX_b and PY_b from the control of relays ZX_b and ZY_b. Under these conditions, the relay R_{b1} will function in response to any change in the over-all equivalent at the frequency f_1 to adjust the potentiometer EP_b to restore the equivalent to normal at that frequency. At the same time, the relay R_{b2} may function, in case the channels are not all at the same level, to adjust the equalizer EZ_b to restore the slope of the attenuation frequency curve to a horizontal condition. In this case, it will also be understood that the adjustments may be made manually from readings of the meters M_1 and M_{12} if desired.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention, as defined in the following claims.

What is claimed is:

1. In a multi-frequency transmission system, the method of equalization of the transmission over a range of frequencies, which consists in transmitting two pilot frequencies over the system, observing the amplitude of each of the pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, and introducing losses into the circuit which vary with frequency in accordance with a curve whose slope is complemental to that of the observed attentuation-frequency characteristic to make the transmission equivalent of the system the same for all frequencies.

2. In a multi-frequency transmission system, the method of obtaining a constant transmission equivalent for a range of frequencies, which consists in transmitting two pilot frequencies over the system, observing the amplitude of each of the pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, introducing losses into the circuit which vary with frequency in accordance with a curve whose slope is complemental to that of the observed attenuation-frequency characteristic to make the transmission equivalent of the system the same for all frequencies, and adjusting the gain of an amplifier in the system in accordance with the observed amplitude of at least one of said pilot frequencies in order to bring the transmission equivalent for all frequencies to a desired value.

3. In a multi-frequency transmission system, the method of equalization of the transmission over a range of frequencies, which consists in transmitting two pilot frequencies over the system, observing the difference between the amplitudes of the pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, and introducing losses in the circuit which vary with frequency in accordance with a curve whose slope is complemental to that of the observed attenuation-frequency characteristic to make the transmission equivalent of the system the same for all frequencies.

4. In a multi-frequency transmission system, the method of obtaining a constant transmission equivalent for a range of fre-

quencies, which consists in transmitting two pilot frequencies over the system, observing the difference between the amplitudes of the pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, introducing losses in the circuit which vary with frequency in accordance with a curve whose slope is complemental to that of the observed attenuation-frequency characteristic to make the transmission equivalent of the system the same for all frequencies, observing the absolute amplitude of at least one of said pilot frequencies as received, and adjusting the gain of an amplifier in the system in accordance with the observed amplitude of said frequency in order to bring the transmission equivalent for all of the frequencies to the same value.

5. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the amplitude of each of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, networks adapted to be combined in various combinations to produce attenuation-frequency characteristics having various slopes, and means to interpolate in the system a combination of networks having a slope to compensate for the indicated slope of the system.

6. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the amplitude of each of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, networks adapted to be combined in various combinations to produce attenuation-frequency characteristics having various slopes, means to interpolate in the system a combination of networks having a slope to compensate for the indicated slope of the system, an amplifier in the system, and means to adjust the gain of said amplifier in accordance with the observed amplitude of at least one of said pilot frequencies.

7. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the difference between the amplitudes of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, networks adapted to be combined in various combinations to produce attenuation-frequency characteristics having various slopes, and means to interpolate in the system a combination of networks having a slope to compensate for the indicated slope of the system.

8. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the difference between the amplitudes of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, networks adapted to be combined in various combinations to produce attenuation-frequency characteristics having various slopes, means to interpolate in the system a combination of networks having a slope to compensate for the indicated slope of the system, means to indicate the absolute amplitude of at least one of said pilot frequencies, an amplifier in the system, and means to adjust the gain of said amplifier in accordance with the observed amplitude of said frequency.

9. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the difference between the amplitudes of said pilot frequencies to determine the slope of the attenuation-frequency characteristic of the system, networks adapted to be combined in various combinations to produce attenuation-frequency characteristics having various slopes, and means automatically controlled by said indicating means to interpolate in the system a combination of networks having a slope to compensate for the indicated slope of the system.

10. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the difference between the amplitudes of said pilot frequencies to determine the slope of the attenuation-frequency characteristic of the system, networks adapted to be combined in various combinations to produce attenuation-frequency characteristics having various slopes, means automatically controlled by said indicating means to interpolate in the system a combination of networks having a slope to compensate for the indicated slope of the system, a second indicating means to indicate the absolute amplitude of at least one of said pilot frequencies, an amplifier in said system, and means automatically controlled by said second indicating means to adjust the gain of said amplifier in accordance with the observed amplitude of said frequency.

11. In a multi-frequency transmission system, means to transmit two pilot frequencies over said system, means to indicate the amplitude of each of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, a group of networks comprising a basic network and a plurality of subordinate networks each having similar characteristics, and means to combine said fundamental network and various ones of said subordinate networks to produce attenuation-frequency characteristics of different slopes, and means to select a combination of networks having such slope as to compensate for the indicated slope of the system.

12. In a multi-frequency transmission sys-

tem, means to transmit two pilot frequencies over said system, means to indicate the amplitude of each of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, a group of networks comprising a basic network and a plurality of subordinate networks each having similar characteristics, and means to combine said fundamental network and various ones of said subordinate networks to produce attenuation-frequency characteristics of different slopes, and means automatically controlled by said indicating means to select a combination of networks having such slope as to compensate for the indicated slope of the system.

13. In a multi-frequency transmission system whose attenuation increases with frequency, means to transmit two pilot frequencies over said system, means to indicate the amplitude of each of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, a group of networks comprising a basic network whose attenuation decreases with frequency and a plurality of subordinate networks whose attenuation increases with frequency, means to combine said basic network and said subordinate networks in various combinations to produce resultant attenuation-frequency characteristics having various slopes and with attenuations decreasing with frequency, and means to select a combination of networks having such slope as to compensate for the indicated slope of the system.

14. In a multi-frequency transmission system whose attenuation increases with frequency, means to transmit two pilot frequencies over said systems, means to indicate the amplitude of each of said pilot frequencies after transmission to determine the slope of the attenuation-frequency characteristic of the system, a group of networks comprising a basic network whose attenuation decreases with frequency and a plurality of subordinate networks whose attenuation increases with frequency, means to combine said basic network and said subordinate networks in various combinations to produce resultant attenuation-frequency characteristics having various slopes and with attenuations decreasing with frequency, and means automatically controlled by said indicating means to select a combination of networks having such slope as to compensate for the indicated slope of the system.

In testimony whereof, I have signed my name to this specification this 27th day of January 1928.

ESTILL I. GREEN.