Jan. 14, 1930. L. M. ILGENFRITZ 1,743,141

EQUALIZATION OF CARRIER SYSTEMS

Filed Jan. 28, 1928 4 Sheets-Sheet 1

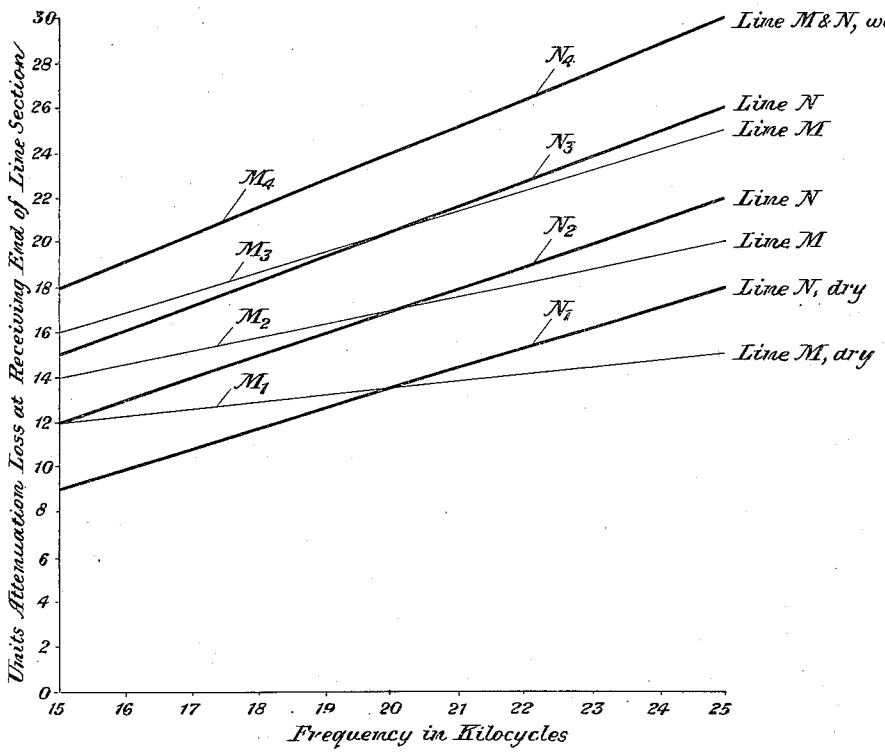


Fig. 1

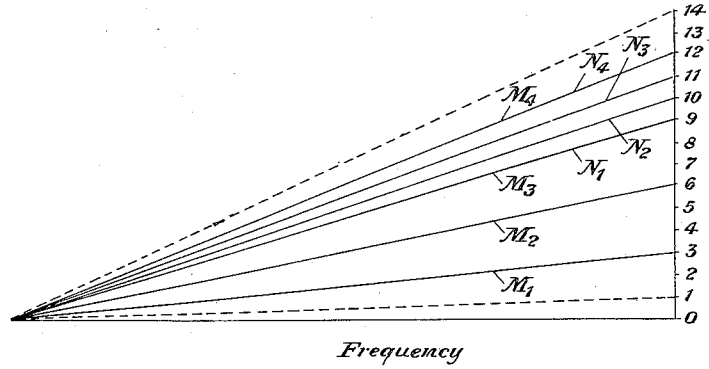


Fig. 2

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EQUALIZATION OF CARRIER SYSTEMS

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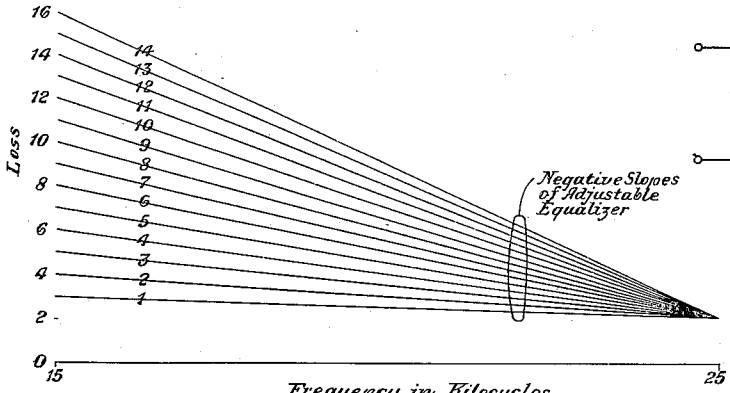


Fig. 3

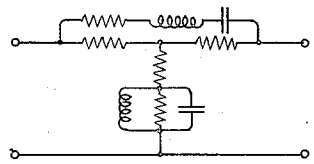


Fig. 5

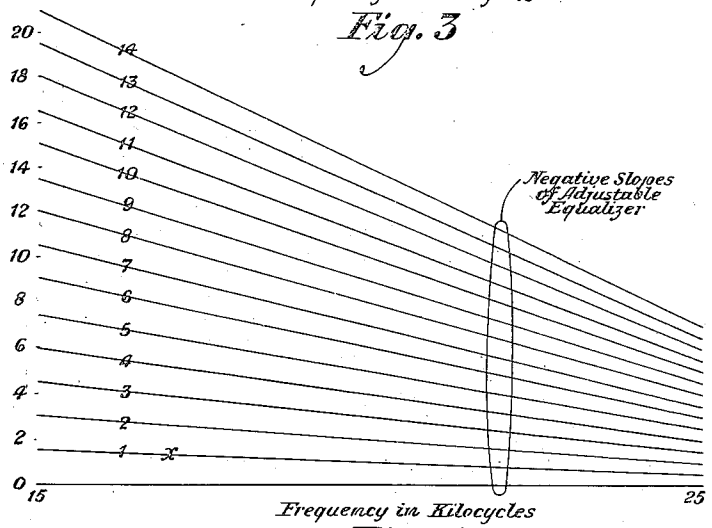


Fig. 4

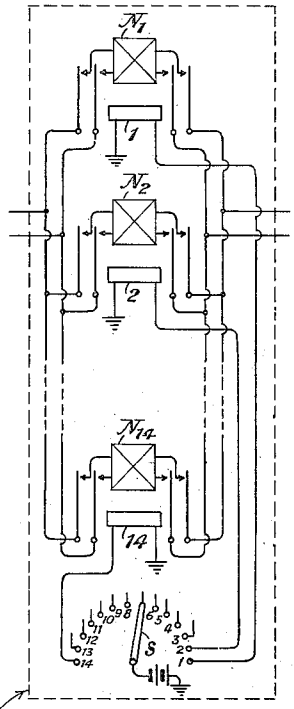


Fig. 8

Adjustable Equalizers

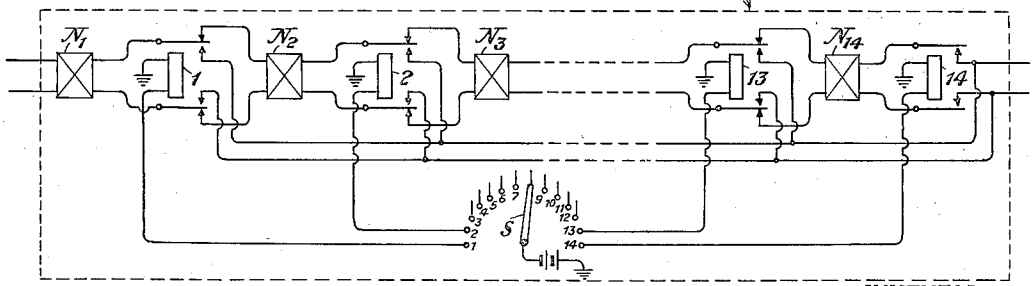


Fig. 9

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EQUALIZATION OF CARRIER SYSTEMS

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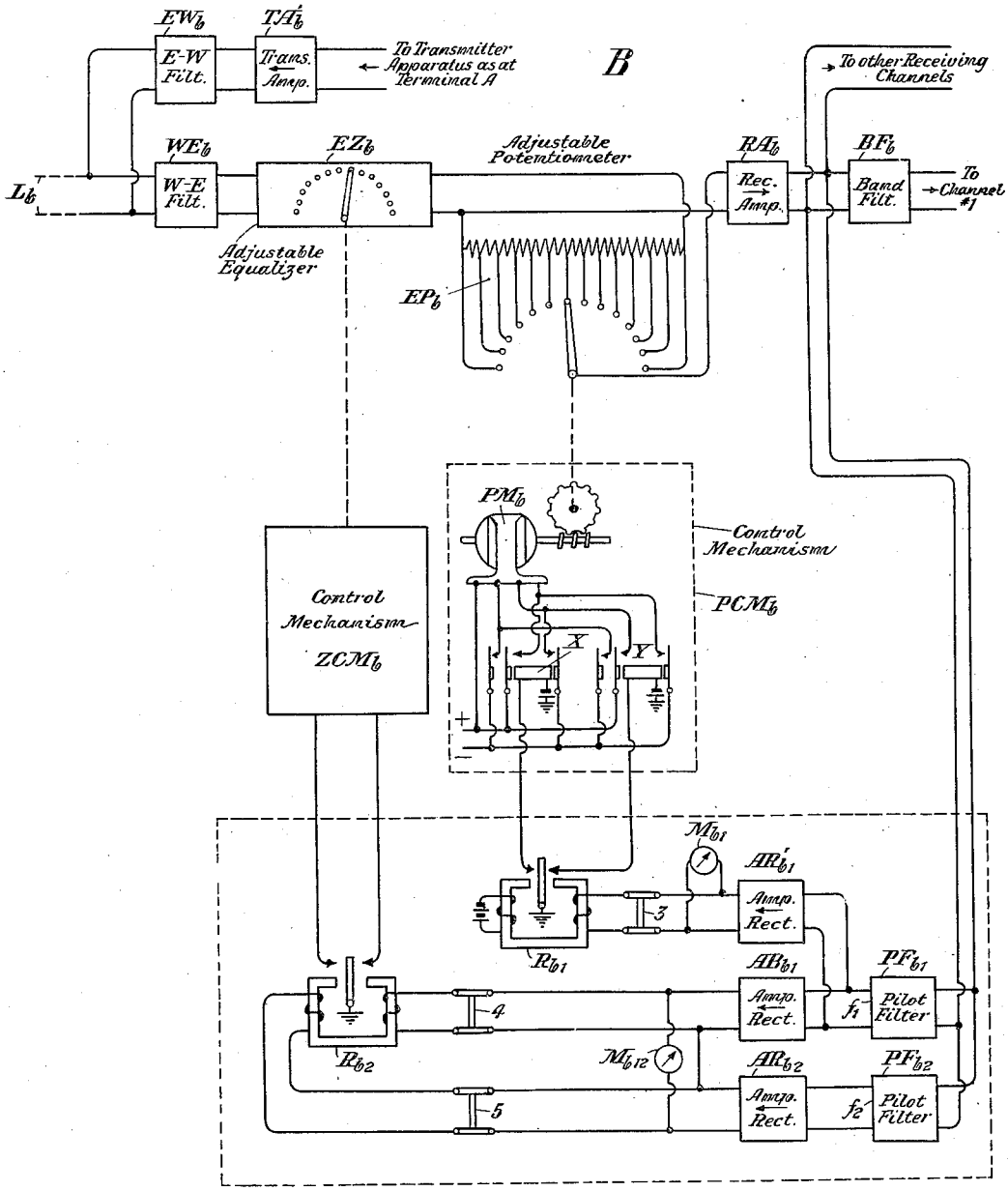


Fig. 6a

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EQUALIZATION OF CARRIER SYSTEMS

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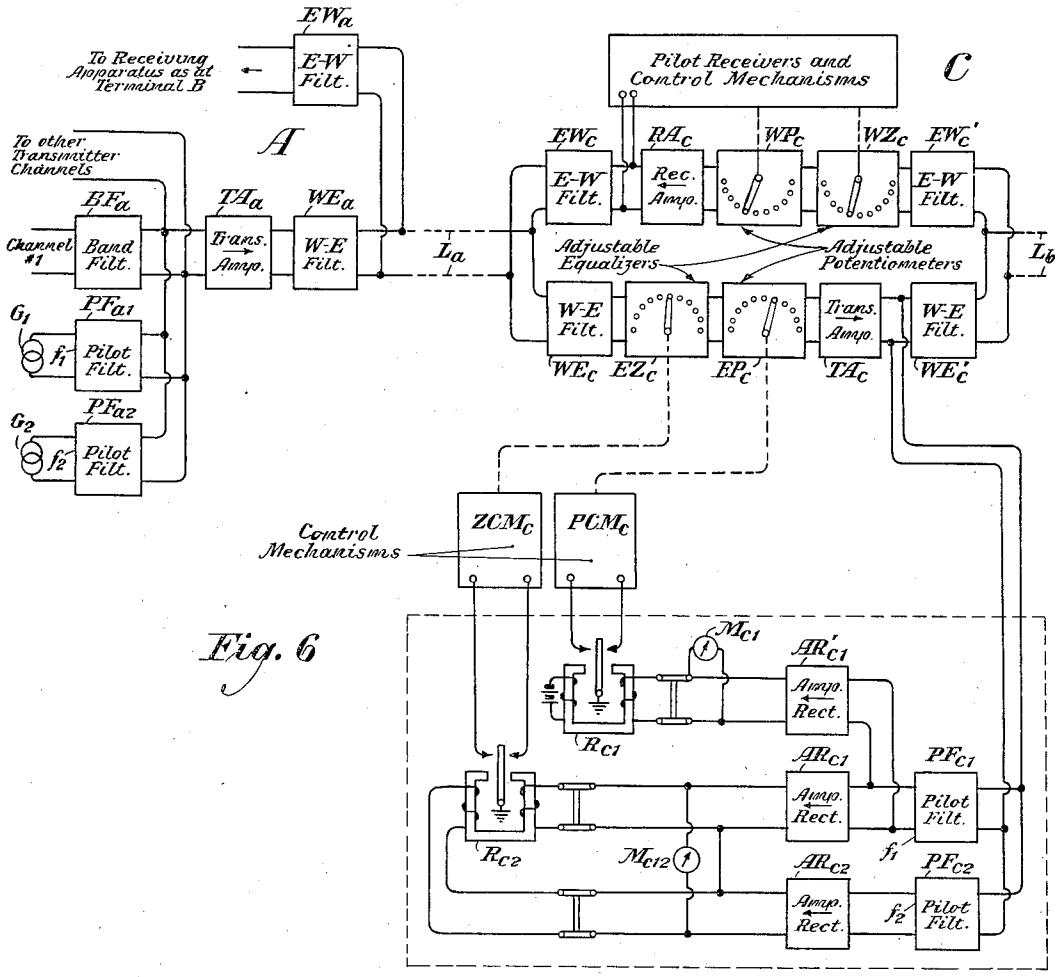


Fig. 6

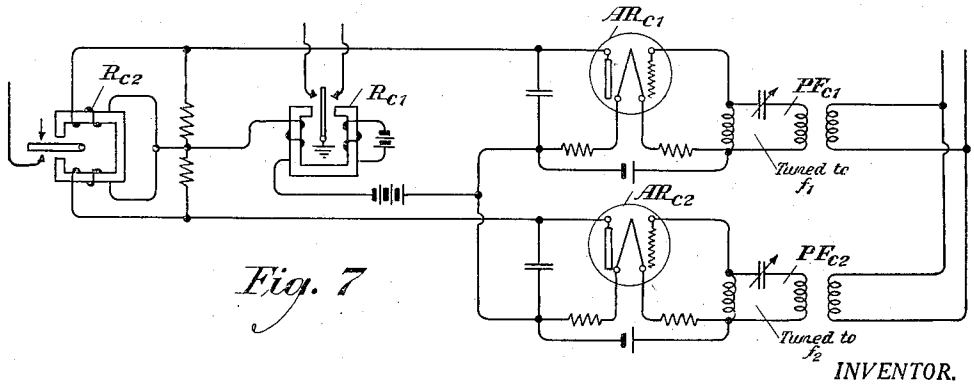


Fig. 7

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UNITED STATES PATENT OFFICE

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EQUALIZATION OF CARRIER SYSTEMS

Application filed January 28, 1928. Serial No. 250,194.

This invention relates to the equalization of carrier systems so that all of the channels will be brought to substantially a common transmission level, and if desired, 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 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 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 attention 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 corrector 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 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 equalizer networks having attenuation-frequency characteristics whose slopes pass through a common point at one frequency; Fig. 4 shows a similar set of curves by means of which the same slopes may be obtained but in which the curves do not pass through a common level at one of the pilot frequencies; Fig. 5 illustrates a type of network which may be used for obtaining any of the desired slopes illustrated in Figs. 3 and 4; Figs. 6 and 6ª, taken together, illustrate a circuit arrangement for carrying out the principles of the invention; Figs. 8 and 9 illustrate two different forms of adjustable equalizers which may be used in connection with the invention; while Fig. 7 illustrates a modified form of pilot receiver apparatus enabling simultaneous adjustment of the potentiometer and slope compensator.

Referring to Fig. 1, let us suppose we have a transmission line which we will call M, and that we transmit over this line several 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 attentuation 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 attentuation measurement 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 a repeater, (which changes 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 affects 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, on 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 or 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 obtain the desired range of slope adjustment would be to have a set of networks, each so designed as to have an attenuation-frequency characteristic corresponding to a different one of the curves of Fig. 3. These networks may be of the type illustrated in Fig. 5 and would preferably be so designed that their slopes all pass through a common level at one of the pilot frequencies. The characteristics of this type of network are discussed at length in the patent to Zobel, No. 1,603,305 of October 19, 1926. If desired, instead of using a separately designed network for each slope, a series of identical networks, each having a slope indicated by the curve x of Fig. 4, may be designed and, by connecting different numbers of these networks in tandem, various slopes illustrated in Fig. 4 may be obtained.

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 the 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. 6 and 6ª, 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 station 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 are passed through pilot filters or selecting devices PF_{a1} and PF_{a2}, respectively. These pilot frequencies then pass to the line through the transmitting amplifier and directional filter which carry the carrier channels. Only the transmitting apparatus is shown at station A.

At each repeater station, the usual repeater apparatus will be provided and at the terminal station B carrier transmitting and receiving apparatus of known type will be employed. Also there will be provided at the terminal station B and at suitable intermediate points, such as repeater stations, pilot apparatus for controlling the adjustments of the potentiometer and frequency equalizer. For example, at station B, 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 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 described 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 C, 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 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 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 potentiometer EP_c similar to that described in station A. The east-west path likewise includes an equalizer EZ_c which may be similar to the corresponding equalizer at station B. Similarly, the east-west path includes a common amplifier RA_c controlled by the potentiometer WP_c. The path also includes an equalizer WZ_c similar to the equalizer EZ_c.

In order to adjust the potentiometer EP_c at station C, one of the pilot frequencies f_1 is selected 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 this 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 upon whether there is an increase or decrease in received current. This operates the mechanism PZM_c to shift the adjustable switch of the potentiometer EP_c.

As the potentiometer and control mechanism at station C are in detail similar to the potentiometer EP_b and control mechanism PZM_b at station B, it will be obvious that the operation of the armature of the relay R_{c1} will energize one of the relays corresponding to X and Y of Fig. 6a, thereby operating the motor corresponding to PZM_b in either a forward or reverse direction, depending upon which way the armature of the relay is acting. This motor is 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 decreased to such a point that the received pilot frequency is restored to its normal amplitude.

Since the potentiometer EP_c consists of resistance steps, it produces the same change in gain at all the carrier frequencies involved. In order to compensate for the difference in the level of the various channels, or, in other words, in order to compensate for the slope of the attenuation-frequency characteristic, the adjustable equalizer EZ_c is arranged to be

controlled by a control mechanism ZCM_c similar to that already described. Frequencies f_1 and f_2 are selected by the pilot filters PF_{c1} and PF_{c2} and are then separately impressed upon amplifier-rectifier units AR_{c1} and AR_{c2}, respectively. The rectified direct currents from these amplifier-rectifier units are combined in opposing relation upon the windings of relay R_{c2} to actuate the control mechanism ZCM_c. The pull upon the armature of this relay will be proportional to the difference between the magnitudes of the two pilot frequencies as received at station C. The pull upon the armature will therefore be a measure of the slope of the attenuation-frequency curve for the circuit extending from station A to station C and will be independent of the absolute amplitudes of the two pilot frequencies.

The control mechanism ZCM_c will, of course, be similar to that illustrated in Fig. 6[a] at PCM_b and will automatically adjust the switch of the equalizer EZ_c to bring all of the channels to the same level as will be described later. It will also be understood that arrangements will be provided in connection with the east-west path of the repeater to control the adjustment of the potentiometer WP_c and the equalizer WZ_c through similar pilot frequencies transmitted in the opposite direction. These arrangements will, of course, be in all respects, similar to those described in the west-east path. So, also, at station B, the received pilot frequency f_1 will actuate the relay R_{b1} to operate the control mechanism PCM_b to adjust the potentiometer EP_b. Likewise, the pilot frequencies f_1 and f_2 will be combined in opposition at station B to operate the relay R_{b2} in a manner similarly described in R_{c2} at station C. The relay R_{b2} will actuate the control mechanism ZCM_b to adjust the equalizer EZ_b. In the arrangement above described, the pilot apparatus at station C produces the necessary eqaulization and potentiometer adjustments to compensate for the variable transmission losses between station A and station C, while the corresponding apparatus at station B performs a similar function with respect to the section of the circuit extending from station C to station B.

Where the adjustable equalizers such as EZ_c and EZ_b are to function to 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 the purpose of illustration, shown as comprising fourteen. Each of these contact positions corresponds to one of the curves 1 to 14, inclusive, of Fig. 3. Switching relays 1 to 14, inclusive, are associated with the contacts 1 to 14 of the controlling switch for the purpose of switching individual networks N_1 to N_{14} into the line circuit. Each of these networks will be differently designed so that each will have the attenuation-frequency characteristic whose slope will correspond to a different one of the curves of Fig. 3.

The effect of the adjustment of switch S of Fig. 8 is to successively bring different networks into the circuit until a network is selected whose slope is just complemental to that of the existing slope of the line circuit. When the proper network has been selected, both pilot frequencies will be received over the line and through the network at the same level so that the relay R_{c2} or R_{b2}, as the case may be, will have its armature restored to its neutral position and further adjustment of the equalizer will not take place.

Where the slopes of all of the networks N_1 to N_{14}, inclusive, pass through a common point at one of the pilot frequencies or, in other words, the loss introduced by each of the networks is the same at one pilot frequency different networks may be switched into or out of the circuit without changing the amplitude of that pilot frequency as received. As shown in Fig. 3, the networks are all designed so that they have a similar loss at, for example, 35 kilocycles. If this figure is to be used as the frequency f_1 of the system, as above described, the adjustment of the equalizer will have no effect upon the amplitude of the pilot frequency f_1. Therefore, if the actual amplitude of the frequency f_1 as received is above or below normal, the relay R_{c1} at station C and the relay R_{b1} at station B, as the case may be, will operate its corresponding control mechanism to adjust the potentiometers EP_c and EP_b, respectively. This results in raising or lowering the then existing level at the pilot frequency f_1 to a desired normal level.

Briefly stated, the operation of the equalizer at each station is to bring all of the channels to a common level as received at that station. The potentiometer at that station is also adjusted so as to raise or lower the common level to a preassigned normal level for the system. Since the adjustment of the equalizer does not affect the amplitude of the pilot frequency which controls the potentiometer, the adjustment of the potentiometers and equalizers may take place simultaneously and are wholly independent.

Instead of having the slopes of all of the equalizer networks pass through a common point, as shown in Fig. 3, it will facilitate the design of the networks to have the slopes pass through different points at both pilot frequencies and make up the desired compensating slope from different combinations of networks of identical design. For example, as shown in Fig. 4, each network might be designed to have a slope indicated

by the curve x of Fig. 4. By combining in tandem various numbers of these networks, the various equalizer slopes of Fig. 4 will then be obtained.

Where the equalizer networks are to be combined in tandem, as above described, the equalizer circuit might be arranged as shown in Fig. 9. Here, again, the switch S may have fourteen contact points, one corresponding to each desired slope. Each contact point controls the circuit of one of the relays 1 to 14, inclusive. The relay contacts are so arranged that if none are energized, all of the networks N_1 to N_{14}, inclusive are connected in tandem over the back contacts of the relays. The network N_1 is permanently connected to the line terminals at the left. Whenever a 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 terminal at the right.

For example, if it is desired to compensate for the slope indicated at 1 in Fig. 2, the switch S will be moved to position 1 thereby energizing relay 1 which disconnects network N_1 from all the remaining networks and connects said network N_1 directly to the line terminal at the right. If the switch is moved to position 2, relay 1 is deenergized and relay 2 is actuated. This results in disconnecting network N_2 from the networks to the right thereof and connecting it to the line terminal at the right. Network N_2 is, of course, connected in tandem with network N_1 by release of relay 1. This combination will compensate for the slope shown at 2 in Fig. 2. If the switch is moved to position 13, relay 13 is actuated, all of the relays to the left of 13 being deenergized. All of the networks N_1 to N_{13}, inclusive are connected in tandem. The relay 13 disconnects the networks from network N^{14} and connects them directly to the line terminals at the right. This gives a combination which will compensate for the slope 13 of Fig. 2.

As above described, the operation of adjusting the potentiometer and equalizer are accomplished automatically. In some cases, however, it may be desired to adjust the switches of the potentiometers and equalizers manually. For example, at the terminal station in Fig. 6[a], the switches 3, 4 and 5 may be opened. The control mechanism will now cease to function and the attendant will merely read the meter M_{b12} and adjust the switch of the equalizer EZ_b until the reading of the meter is normal. The meter M_{b1} will then be read and the switch of the potentiometer adjusted until the meter M_{b1} indicates a normal reading. The adjustment of the equalizer brings all channels to the same level so that pilot frequencies have the same amplitude. The adjustment of the potentiometer brings the now common level of all the channels to the desired normal level.

In a similar manner, the switches corresponding to 3, 4 and 5 in Fig. 6 may be opened and the adjustment of the potentiometer and equalizer at station C be accomplished manually from the readings of the meters M_{c1} and M_{c12}. In general, of course, where the adjustments are to be made manually, the station nearest the source of pilot frequencies would make the adjustments first, so that from each station the pilot frequencies, as they are sent out towards the next station, will have the same amplitude. If this were not done and one of the stations further along the line as, for example, the terminal station should attempt to make the adjustment first, such terminal station would necessarily have to make adjustments for the entire change in level throughout the system. Notwithstanding this adjustment at the terminal, however, the slope would still be abnormal at intermediate stations such as C and if the attendant at such intermediate station should thereafter make a compensation to render the slope horizontal, the slope would be correspondingly changed at the terminal and would have to be readjusted there.

It will be clear that when the system operates in accordance with the principles of Fig. 4, the equalizer adjustment will change the loss at the pilot frequency f_1 and hence change the received amplitude of the pilot frequency f_1 which controls the potentiometer. In order to avoid any interference between the operations of adjusting the potentiometer and the equalizer, the pilot receiving circuit may be arranged as in Fig. 7. Here the pilot frequencies f_1 and f_2 are separately impressed upon the amplifier-rectifier units AR_{c1} and AR_{c2} which comprise vacuum tubes whose output circuits are connected in a push-pull relation. The two windings of the relay R_{c2} are connected respectively in the output circuits of the devices AR_{c1} and AR_{c2}. Therefore, the armature of the relay R_{c2} will respond to the difference between the amplitudes of the frequencies f_1 and f_2 as received. The relay R_{c2} functions to actuate the control mechanism to adjust the equalizer until the slope of the overall attenuation-frequency characteristic becomes horizontal.

The potentiometer controlling relay R_{c1}, however, is connected in the common branch of the two output circuits and is therefore actuated by the sum of the two rectified currents produced from the frequencies f_1 and f_2. The response of the relay R_{c1} is therefore, in effect, proportional to the amplitude of a frequency midway between the frequencies f_1 and f_2. A consideration of the curves of Figs. 1 and 4 will show that if the pilot frequencies be taken as 15 kilocycles and 25 kilocycles, respectively, this medium frequency will correspond to 20 kilocycles and,

in effect, the losses at this frequency will determine the setting of the potentiometer. Such potentiometer setting may take place simultaneously with the setting of the equalizer without the one interfering with the other.

It will be understood, of course, that where the system is to be operated according to the principles illustrated by the curves of either Fig. 3 or Fig. 4, the apparatus of Fig. 7 may be employed at both the repeater station and the terminal station.

It will be obvious that the general principles herein disclosed may be employed 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 comprising a plurality of line sections connected in tandem, the method of equalization of the transmission over a range of frequencies, which consists in transmitting two pilot frequencies over the entire system, observing the amplitude of each of the pilot frequencies after transmission over each section to determine the slope of the attenuation-frequency characteristic of each section, and introducing losses into each section which vary with frequency in accordance with curves whose slopes are complemental to those of the observed attenuation-frequency characteristics of the several sections, to make the transmission equivalent of any section of the system the same for all frequencies.

2. In a multi-frequency transmission system comprising a plurality of line sections connected in tandem, the method of obtaining a constant transmission equivalent for a range of frequencies, which consists in transmitting two pilot frequencies over the entire system, observing the amplitude of each of the pilot frequencies after transmission over each section to determine the slope of the attenuation-frequency characteristic of each section, introducing losses into each section which vary with frequency in accordance with curves whose slopes are complemental to those of the observed attenuation-frequency characteristics of the several sections, to make the transmission equivalent of any section of the system the same for all frequencies, and adjusting the gain of an amplifier in each section in accordance with the observed amplitude of at least one of said frequencies after passing over each section.

3. In a multi-frequency system, a plurality of line sections connected in tandem, means to transmit two pilot frequencies over all of the sections of said system, means associated with each section to indicate the amplitude of each of said pilot frequencies after transmission over each section to determine the slope of the attenuation-frequency characteristic of each section, and means to interpolate in each section a combination of networks, each combination having a slope to compensate for the indicated slope of the corresponding line section.

4. In a multi-frequency system, a plurality of line sections connected in tandem, means to transmit two pilot frequencies over all of the sections of said system, means associated with each section to indicate the amplitude of each of said pilot frequencies after transmission over each section to determine the slope of the attenuation-frequency characteristic of each section, means to interpolate in each section a combination of networks, each combination having a slope to compensate for the indicated slope of the corresponding line section, an amplifier in each section, and means to adjust the gain of each amplifier in accordance with the observed amplitude of at least one of said pilot frequencies after passing over the section corresponding to the amplifier.

5. 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 plurality of networks the attenuation of each of which decreases with increase in the frequency, and means to interpolate said networks in said system in such combination as will compensate for the observed slope of the attenuation-frequency characteristic of the system.

6. 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 plurality of networks the attenuation of each of which decreases with increase in the frequency, means to interpolate said networks in said system in such combination as will compensate for the observed slope of the attenuation-frequency characteristic of the system, amplifying means associated with said system, and means to adjust the amplifying means in accordance with the observed amplitude of at least one of said pilot frequencies.

7. 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, an equalizer including a plurality of networks, each of said networks having an

attenuation which varies with frequency but which is the same for all of said networks at one of said pilot frequencies, and means to interpolate said networks in said system in such combination as will compensate for the observed slope of the attenuation-frequency characteristic of the system.

8. 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, an equalizer including a plurality of networks, each of said networks having an attenuation which varies with frequency but which is the same for all of said networks at one of said pilot frequencies, means to interpolate said networks in said system in such combination as will compensate for the observed slope of the attenuation-frequency characteristic of the system, amplifying means associated with said system, and means to adjust said amplifying means in accordance with the observed amplitude of at least one of said pilot frequencies.

9. In a multi-frequency transmission system whose attenuation varies with frequency, an adjustable equalizer adapted to be adjusted to compensate for the variation of the attenuation of the system with frequency, an adjustable transmission device for raising and lowering the transmission level of the system, means to transmit two pilot frequencies over said system, means to indicate the difference between the amplitudes of the pilot frequencies after transmission, means to control said adjustable equalizer in accordance with the indicated difference, means to indicate the sum of the amplitudes of the two pilot frequencies after transmission, and means to control said adjustable transmission device in accordance with the indicated sum.

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

LESTER M. ILGENFRITZ.