Sept. 19, 1933. R. H. LINDSAY 1,927,128

GAIN CONTROL APPARATUS

Filed Dec. 2, 1931 2 Sheets-Sheet 1

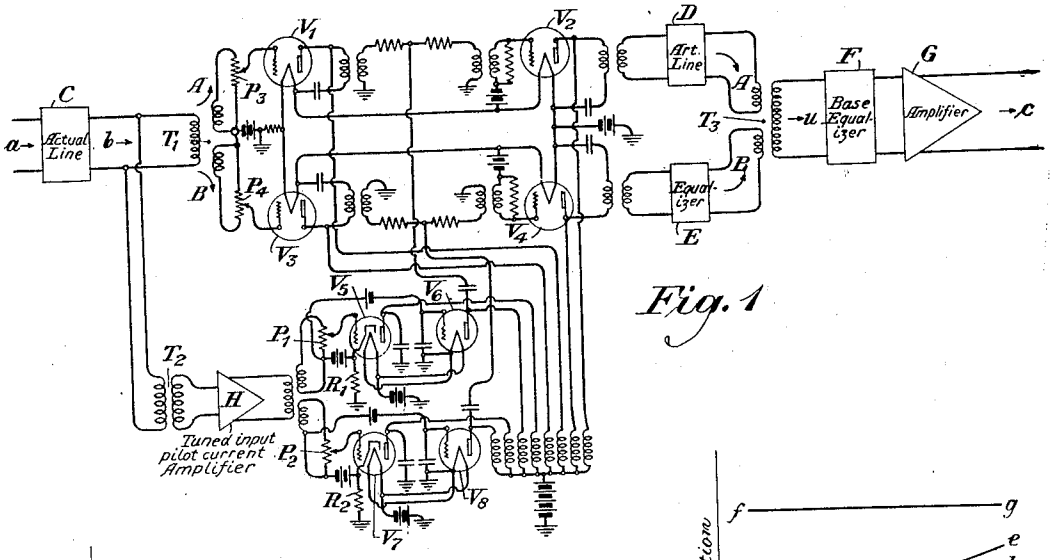

Fig. 1

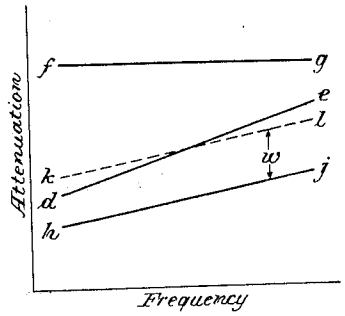

Fig. 2

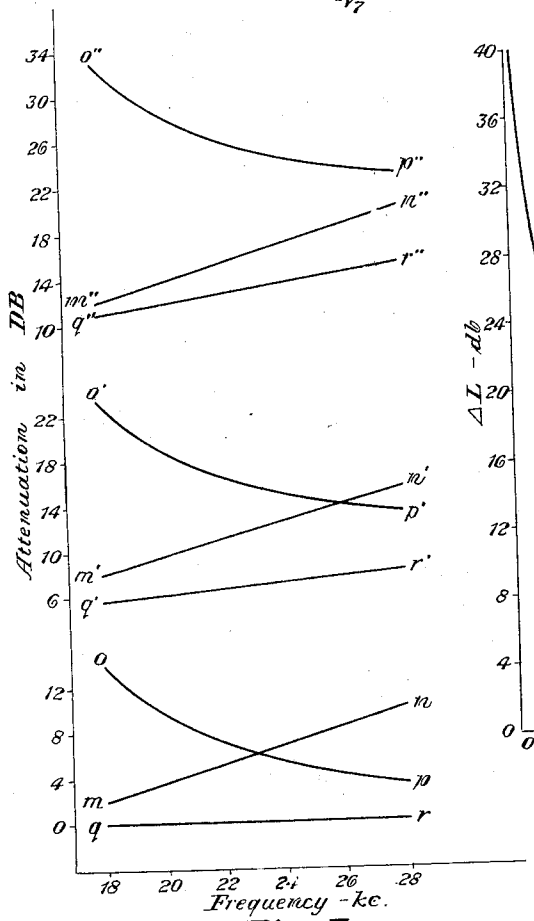

Fig. 3

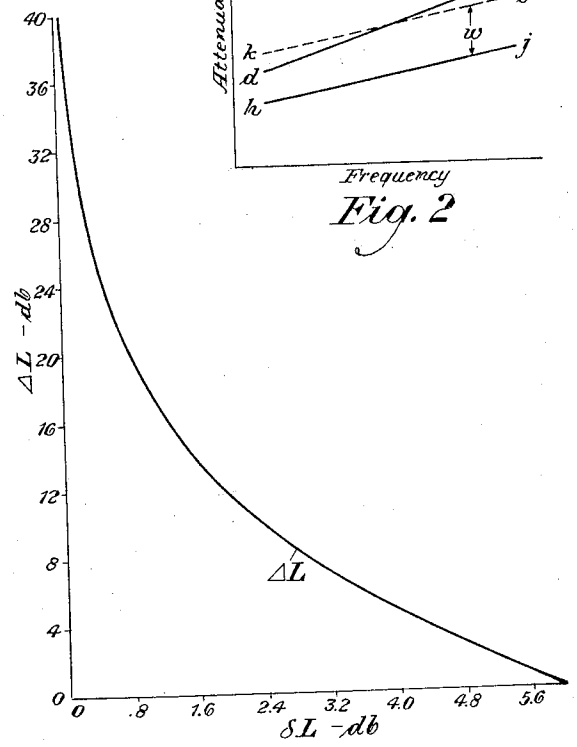

Fig. 4

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GAIN CONTROL APPARATUS

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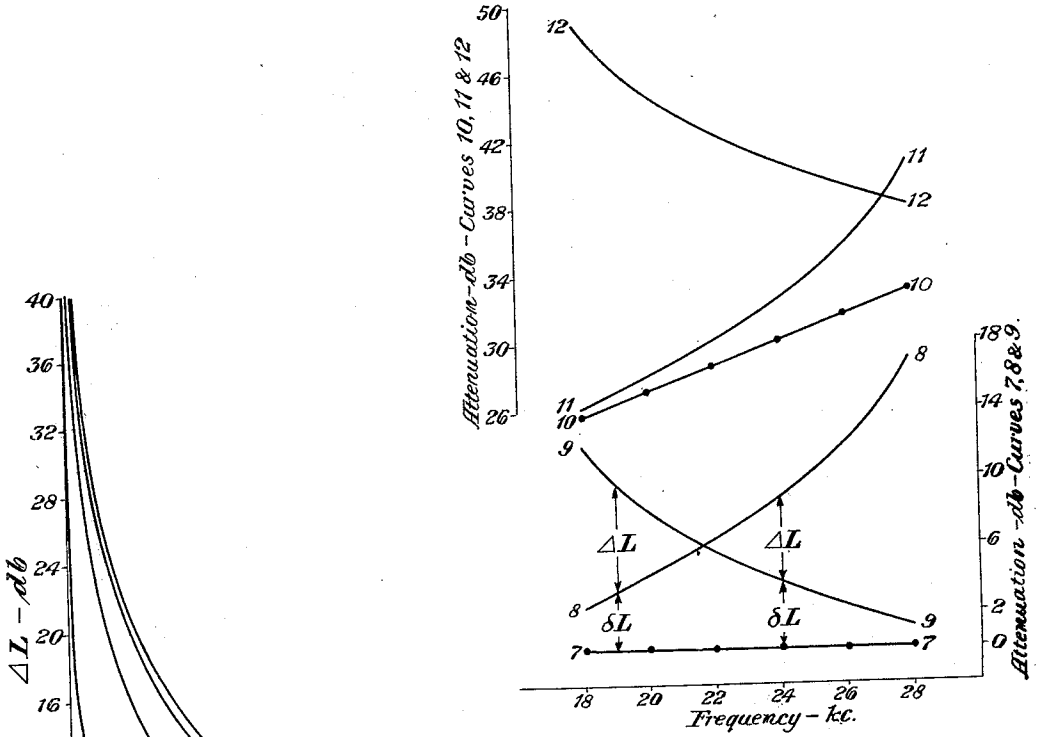

Fig. 5

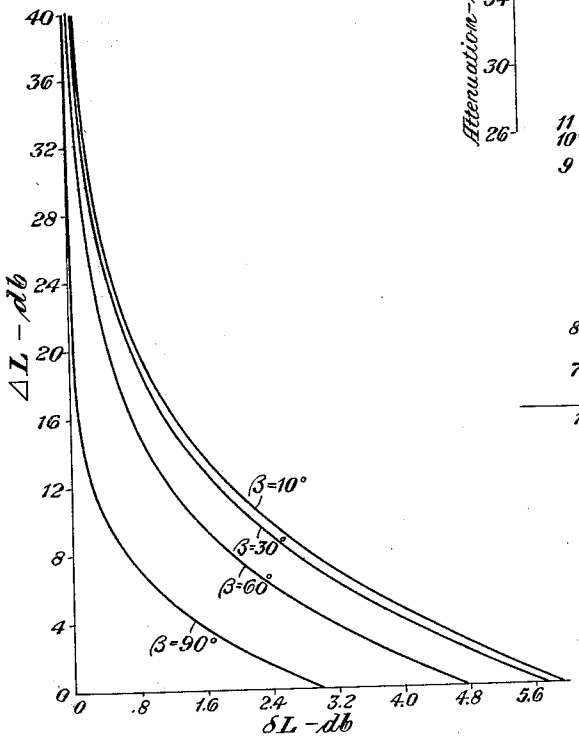

Fig. 6

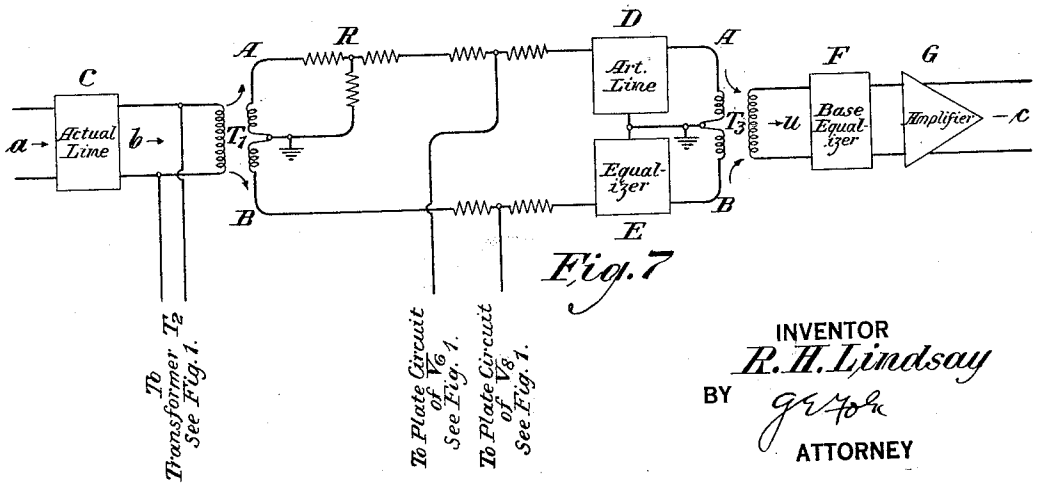

Fig. 7

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UNITED STATES PATENT OFFICE

1,927,128

GAIN CONTROL APPARATUS

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Application December 2, 1931. Serial No. 578,603

16 Claims. (Cl. 178—44)

This invention relates to transmission systems. More particularly, it relates to arrangements for controlling the gain as well as the equalization of transmission systems.

One of the objects of this invention is to maintain the attenuation for a signaling system constant under variable conditions of weather by changing the attenuation characteristic of the system in accordance with changes in weather.

This invention involves the operation in parallel of two amplifiers which have different gain frequency characteristics. The resultant characteristic will be given a shape dependent upon the characteristics of the individual amplifiers. This shape may be controlled within certain limits by the proper design of the amplifier characteristics, for by shifting these characteristics simply by varying the gain of the two amplifiers, the resultant characteristic may be made to simulate either a continuously variable artificial line or a continuously variable equalizer, as desired. This invention may, therefore, have a number of applications in telephone systems and other systems especially where continuously variable attenuation or equalization is desired as against variations step-by-step, or where variable attenuation or equalization is desired without mechanical devices or moving parts.

This invention will be described with particular reference to a pilot channel for a carrier telephone system in which one side band representing signals is transmitted, the other side band and the carrier being suppressed, but it will be clearly understood that this invention is applicable to other systems as well.

It is well to bear in mind that the present apparatus for automatic control of gain and equalization at repeater and terminal stations of carrier signaling systems, makes use of several types of mechanical devices including selectors, relays and control meters. It is believed that considerable improvement in such equipment in the direction of simplifying the operation of the circuit, improving its reliability, and decreasing the cost of maintenance could be obtained if all the mechanical control equipment were eliminated and its functions performed by vacuum tube equipment having no moving parts whatever. The circuits of two parallel amplifiers which form the basis of this invention, have been set up to meet these conditions.

This invention will be better understood from the detailed description hereinafter following, when read in connection with the accompanying drawings in which Figures 1 and 7 represent circuits suitable for carrying out the principles of this invention and Figs. 2 to 6 show curves employed to explain certain of the features of the invention.

Fig. 1 shows a transmission circuit having an input at *a* and an output at *c*. The input at *a* may be considered to consist of currents of a number of different magnitudes and frequencies within certain limits, as is the case in a carrier telephone system. The input at *a* might also be considered to include a pilot current, i. e., a current having a frequency ordinarily beyond the limits of the frequencies comprising the transmitted side bands, and the pilot current generally has a constant frequency and magnitude at the transmitting terminal and is transmitted for the purpose of automatically regulating the gain and equalization at the several amplifying points of the system.

The currents transmitted at *a* pass over a section of line which may be either open-wire or cable. In the following description the line has been assumed to be of the open-wire type and is represented by a box designated C. Upon arriving at *b* the transmitted currents have ordinarily become subjected to the attenuation-frequency characteristics of the lines C. Assume that the characteristic *de* of Fig. 2 represents the one for maximum wet weather conditions. Then the function of the equipment at the repeater or receiving terminal is to equalize this characteristic by means of a base equalizer which is generally shown by the reference character F, the base equalizer being employed for producing a resultant characteristic such as *fg* of Fig. 2, and in that event, all frequencies will be amplified uniformly by means of an amplifier in order to properly restore the original output level. It is also the function of the regulating equipment to maintain the same resultant uniform attenuation *fg* when the weather conditions improve, in which event the attenuation characteristic of the line may drop to the curve *hj* of Fig. 2. This may be accomplished by adding artificial attenuation equivalent to the difference between the magnitudes determined by the lines *de* and *hj*. Hence, the level at *c* will be maintained practically identical at all frequencies with that at *a*. In accordance with this invention these functions will be performed by vacuum tube equipment which will be free of moving parts.

The input at *b* enters a transformer T_1 and then divides into two branches A and B. Each portion passes through an amplifier which includes two tubes V_1 and V_2 in the A branch, and

two tubes V_3 and V_4 in the B branch. The output of the amplifier of the A branch passes through an artificial line D, and that of the amplifier of the B branch through an equalizer E. The artificial line D and the equalizer E are so designed with relation to certain chosen gains of the amplifiers of the A and B branches, respectively, that each of the various frequencies at *b* will be equally amplified and transmitted through the transformer T_3 to the point *u*. In other words, if *mn* of Fig. 3 represents the attenuation characteristic of the A branch between the points *b* and *u*, the attenuation of the B branch being assumed to be infinite, as would be the case if the B branch were open-circuited without changing its input and output impedances, and if *op* be the attenuation characteristic of the B branch between the points *b* and *u*, attenuation of the A branch being considered infinite, then the combined attenuation characteristic between the points *b* and *u* will be represented by the line *qr*. The outputs of the A and B branches are combined and passed through the base equalizer F and through the amplifier G to the point *c*. It is to be noted that the characteristic *op* of Fig. 3 is not a straight line but rather a curve which is concave upwardly. In that respect it differs from the straight line character of the true equalizer characteristic ordinarily used for a section of open-wire line.

Assume now that maximum wet weather conditions prevail. As stated hereinabove, the attenuation of the line C is therefore represented by the characteristic *de* of Fig. 2. Since the characteristic *de* is the one which the base equalizer F must equalize, the portion of the circuit between the points *b* and *u* must have zero loss at all frequencies under these conditions. This will be the case if the resultant characteristic is represented by the line *qr* of Fig. 3.

Assume next that the weather conditions improve to such an extent that the attenuation characteristic of the line C is represented by *hj* of Fig. 2. In order that the conditions at the point *c* may remain the same as before, the circuit must introduce additional attenuation sufficient to raise the overall attenuation between points *a* and *u* to the level determined by the characteristic *de* of Fig. 2. This operation may be considered to consist of two components, the first a distortionless increase in attenuation as shown by the reference character *w* of Fig. 2 which will result in raising the characteristic *hj* to the position shown by the dotted line *kl*, and the second an equalization adjustment resulting in tilting the characteristic *kl* counter-clockwise to the position *de*.

The first of these components may be accomplished by decreasing equally the gain of the amplifiers in the A and B branches by an equal amount corresponding to the magnitude *w* which is the vertical distance representing attenuation between the lines *hj* and *kl*.

The second component which requires an equalization adjustment, may be accomplished by disturbing the proportions of the energy transmitted by the A and B branches. If a larger portion of the energy passes through the equalizer E than through the so-called artificial line D, the attenuation characteristics of the circuit as a whole between points *b* and *u* will partake of that of the equalizer E. If, on the other hand, the greater energy passes through the artificial line D, its effect will predominate and cause the circuit between the point *b* and *u* to look like an artificial line. The latter condition is the desired one in this case since the line *kl* of Fig. 2 must be tilted counter-clockwise to coincide with the line *de*. This may be accomplished by increasing the gain of the amplifier of the A branch and decreasing that of the amplifier of the B branch. The result of these two corrective operations, namely, first an equal decrease in the gain of the branches A and B, and second small increase in the gain of the A branch and a small decrease in the gain of the B branch, is in effect a larger decrease in gain for the B branch than for the A branch.

Should the weather conditions improve still further, both of the required components of gain correction would be correspondingly larger for the amplifiers of the two branches. It will be seen therefore, that in all cases the actual characteristic of the line C must be supplemented by an artificial characteristic so as to always bring about the conditions represented by the line *de* of Fig. 2.

To establish these principles more rigidly, further reference will be made to Fig. 3. Here, the curve *qr*, as previously stated, represents the resultant characteristic of the A branch containing the artificial line D and the B branch containing the equalizer E, for the condition when maximum wet weather prevails.

The change from maximum wet weather to maximum dry weather may involve, for example, a decrease of about 15 db. of attenuation at 28 kc. and about 11 db. at 18 kc. for a section of telephone open wire 300 miles long. The frequency range between 18 and 28 kc. is approximately that of one of the side band groups of one form of carrier telephone system which is used here as an example. Maximum dry weather conditions will therefore require that the characteristic *qr* be raised to the position *q'' r''* in order that the overall attenuation between points *a* and *u* may remain unchanged and exhibit the character represented by the line *de* of Fig. 2. It will be noted that *r''* is 15 db. above *r*, and *q''* 11 db. above *q*. *q'' r''* is the calculated resultant of the curves *m'' n''* and *o'' p''*, *mn* having been raised 10 db. to the new position by a decrease in the gain of the amplifier of the A branch by 10 db., and *op* having been raised 19 db. to the new position by a decrease in the gain of the amplifier of the B branch by 19 db. (Throughout this disclosure the term "db." designates an abbreviation for decibel or decibels.)

The characteristic *q' r'* represents a condition intermediate between the two extremes. It should be particularly noted that *q' r'* is obtained by raising, the curve *mn* 5 db. to the level *m' n'* and similarly raising *op* by 9.5 db. to the level *o' p'*, and that the ratio of these decreases in the gains of the two amplifiers is proportional to those required for the establishment of the characteristic *q'' r''*. In other words, the ratio between the decreases of the amplifier gains may be represented as follows:

$$\frac{5}{9.5}=\frac{10}{19} \qquad (1)$$

A more general equation may be expressed as follows:

$$\frac{\Delta G_{A1}}{\Delta G_{B1}}=\frac{\Delta G_{A2}}{\Delta G_{B2}} \qquad (2)$$

In Equation (2) ΔG_A and ΔG_B are the gain changes of the respective amplifiers. It is to be noted that in the case described hereinabove all values of ΔG_A and ΔG_B are negative, this condition being

one which necessarily follows from raising the loss frequency characteristic, and this corresponds to a falling gain frequency characteristic. It should also be noted that when the ratio of ΔG_A to ΔG_B is less than unity, and the ratio is always required to be less than unity when the weather conditions improve, the resultant characteristic will be that of a truly variable artificial line corresponding to a section of actual line when ΔG_A and ΔG_B are negative. When the ratio of ΔG_A to ΔG_B is greater than unity, both increments remaining negative, the resultant characteristic will be that of a variable equalizer employed for equalizing a variable section of open wire line. It will be apparent that the slope of the characteristic, is, of course, always dependent upon the ratio

$$\frac{\Delta G_A}{\Delta G_B}.$$

The further this ratio departs from unity in either case, the greater will be the slope.

When ΔG_A and ΔG_B both have positive values, the resultant characteristic will show a gain and the circuit becomes equivalent to the amplifier having a gain frequency characteristic of variable slope. If

$$\frac{\Delta G_A}{\Delta G_B}$$

equals unity, the resultant characteristic merely rises or falls, and the slope of the characteristic remains constant. In the matter considered hereinabove, ΔG_A and ΔG_B are always referred to the condition determined by the characteristic *qr* which represents the overall attenuation between the points *b* and *u* of Fig. 1, and this attenuation is zero at all frequencies.

It will be understood that although the two components *mn* and *op*, of which *qr* is the resultant, are chosen so that *mn* is a straight line and *op* concave upwardly, moreover, other component curves having different slopes and shapes may equally well be employed and these may be so chosen that their resultant will vary closely approximately the straight line character of the various curves *qr*, *q' r'* and *q'' r''*. If, for a different purpose, it is desired to produce a true equalizer characteristic instead of an artificial line characteristic, more satisfactory results may be obtained by arranging to have *op* a straight line and *mn* concave upwardly. So, it will be seen that there is considerable latitude in the choice of the individual components which will satisfactorily produce any desired result, and there will be no difficulty in designing the elements forming the branches A and B so that their characteristics may be properly combined for any purpose. However, both components cannot be straight lines if the resultant is to be a straight line and this will be apparent from the description hereinafter following.

It will be evident that if the two component characteristics of the two parallel branches are to be combined as described hereinabove, so as to produce a desired resultant, there must be no difference in the phase distortion between the branches A and B. In other words, the component of voltage at the point *u* contributed by the branch A must be in phase with that contributed by the branch B. This condition will not ordinarily be difficult to obtain. If necessary, however, phase correcting networks of any well known type, may supplement the artificial line D and the equalizer E. Or, if desired, both of the latter elements may be designed to include proper phase correcting networks.

The formula for determining the characteristics *qr*, *q' r'* and *q'' r''* may be calculated as follows:

Let E_i = total input voltage at *b*.

E_R = resultant output voltage at *u*.

E_A = portion of output voltage at *u* contributed by A branch.

E_B = portion of output voltage at *u* contributed by B branch.

L_A = overall loss of A branch from *b* to *u*, B branch attenuation being infinite.

L_B = overall loss of B branch from *b* to *u*, A branch attenuation being infinite.

L_R = resultant overall loss from *b* to *u*.

If the voltages contributed by the A and B branches are in phase, then

$$E_R = E_A + E_B \tag{3}$$

as is well known

$$L_A = -20 \log_{10} \frac{E_A}{E_i} \tag{4}$$

and

$$L_B = -20 \log_{10} \frac{E_B}{E_i} \tag{5}$$

and

$$\frac{E_A}{E_i} = \log^{-1} \frac{-L_A}{20} \tag{6}$$

and similarly

$$\frac{E_B}{E_i} = \log^{-1} \frac{-L_B}{20} \tag{7}$$

and then

$$L_R = -20 \log \frac{E_R}{E_i} \tag{8}$$

or

$$L_R = -20 \log \frac{E_A + E_B}{E_i} \tag{9}$$

or

$$L_R = -20 \log \left(\log^{-1} \frac{-L_A}{20} + \log^{-1} \frac{-L_B}{20} \right) \tag{10}$$

It will be seen that when the loss of either branch, say branch B, is infinite, L_B representing the loss of the branch B, then

$$\log^{-1} \frac{-L_B}{20} = \log^{-1} (-\infty) \tag{11}$$

or

$$\log^{-1} \frac{-L_B}{20} = 0 \tag{12}$$

Substituting zero for the second member of the parenthesis in Equation (10) we get

$$L_R = -20 \log \left(\log^{-1} \frac{-L_A}{20} \right) \tag{13}$$

or

$$L_R = L_A \tag{14}$$

Also, when $L_A = L_B$, both members of the parenthesis of Equation (10) become equal and

$$L_R = -20 \log \left(2 \log^{-1} \frac{-L_A}{20} \right) \tag{15}$$

or

$$L_R = L_A - 6.02 \tag{16}$$

So it will be seen that the resultant loss can never be greater than the smaller of its two components, nor more than 6.02 db. less than the smaller component.

The resultant of two curves as determined by Equation (10) is of course not necessarily a

straight line. In the particular case which has been described, it is desired, referring again to Fig. 3, that the resultant *qr* shall be a straight line for the reasons noted. It is also desired that the other resultant curves *q' r'* and *q'' r''* shall be as nearly straight lines as possible, although of different slope. The slopes of the component curves *mn* and *op* are chosen in this case to secure this objective as nearly as possible. Assuming a resultant *qr* as a straight line for chosen positions of *mn* and *op*, the resultant for different positions of *mn* and *op* tends to depart from a straight line slope. It is therefore of interest to note in connection with a case requiring a greater range of variation than that shown in Fig. 3, how accurately the straight line slope of the resultant can be maintained over a wide range of variation of positions of the components, by properly choosing the slopes of the components.

Referring to Fig. 5, curve 7 is the same desired resultant as *qr* of Fig. 3, under the worst weather conditions. Curves 8 and 9 are the component curves, and it is evident that neither of them is a straight line. The plotted points close to curve 7 are the actual calculated resultant of curves 8 and 9, and deviate not more than 0.1 db. from the desired straight line. Curve 10 is the assumed desired resultant, a straight line, for an extreme attenuation range; it is 28 db. above curve 7 at 28 kc. and 20.6 db. above at 18 kc. In order to obtain curve 10 as nearly as possible, curve 8 is raised 23.7 db. to its new position 11, and curve 9 is raised 36.7 db. to the new position 12. The plotted points close to curve 10 are the resultant of 11 and 12, the maximum deviation from the desired resultant being less than 0.2 db. over the entire range. For intermediate positions between the two extremes, the deviation is of course less.

A more convenient form of Equation (10) for determining the resultant of two loss frequency characteristics may be obtained in terms of δL and ΔL, which are quantities shown in Fig. 5. In this figure the ordinates of curves 7, 8 and 9 represent, respectively, the attenuations L_R, L_A and L_B in db. δL and ΔL are inherently positive in value, their purpose being to aid in calculating and plotting curves. Their equations are therefore stated as follows:

$$\delta L = L_A - L_R \tag{17}$$

and

$$\Delta L = L_B - L_A \tag{18}$$

when

$$L_B > L_A.$$

Moreover,

$$\delta L = L_B - L_R \tag{19}$$

and

$$\Delta L = L_A - L_B \tag{20}$$

when

$$L_A > L_B.$$

Taking the anti-log of the expression given by Equation (10) and dividing by the member 20 we get

$$\log^{-1}\frac{-L_R}{20} = \log^{-1}\frac{-L_A}{20} + \log^{-1}\frac{-L_B}{20} \tag{21}$$

Multiplying both sides of Equation (21) by

$$\log^{-1}\frac{L_A}{20}$$

we get

$$\log^{-1}\frac{L_A - L_R}{20} = 1 + \log^{-1}\frac{L_A - L_B}{20} \tag{22}$$

Substituting in Equation (22) the values of δL and ΔL given by Expression (17) and (18) we get

$$\log^{-1}\frac{\delta L}{20} = 1 + \log^{-1}\frac{-\Delta L}{20} \tag{23}$$

By taking the logs of both sides of Expression (23) it follows that

$$\delta L = 20 \log\left(1 + \log^{-1}\frac{-\Delta L}{20}\right) \tag{24}$$

The same expression results from a similar derivation whenever $L_A > L_B$ and there is no need to distinguish between the two. It need only be noted that for convenience in dealing with actual curves, ΔL should always be taken as positive, as indicated in Fig. 5. Fig. 4 shows a curve for δL and ΔL, plotted from Equation (24).

It has been suggested hereinabove that the voltages $E_A + E_B$ were ordinarily in phase and that substantial phase equality between these voltages might be attained by the proper design of the networks of the artificial line D and the equalizer E. However, substantial phase equality is not a necessary condition for the practice of this invention.

If there be a phase difference between the voltages E_A and E_B the resultant voltage has been found to be represented by the following expression

$$E_R = \sqrt{E^2_A + E^2_B + 2E_A E_B \cos\beta} \tag{25}$$

If both sides of Equation (25) be divided by E_i then

$$\frac{E_R}{E_i} = \sqrt{\left(\frac{E_A}{E_i}\right)^2 + \left(\frac{E_B}{E_i}\right)^2 + 2\left(\frac{E_A}{E_i}\right)\left(\frac{E_B}{E_i}\right)\cos\beta} \tag{26}$$

Substituting the values given by Equations (6) and (7) and (8) for their equivalent terms in Equation (26) we get

$$\log^{-1}\frac{-L_R}{20} = \sqrt{\left(\log^{-1}\frac{-L_A}{20}\right)^2 + \left(\log^{-1}\frac{-L_B}{20}\right)^2 + 2\cos\beta\left(\log^{-1}\frac{-L_A}{20}\right)\left(\log^{-1}\frac{-L_B}{20}\right)} \tag{27}$$

and

$$\log^{-1}\frac{-L_R}{10} = \log^{-1}\frac{-L_A}{10} + \log^{-1}\frac{-L_B}{10} + 2\cos\beta\left(\log^{-1}\frac{-L_A - L_B}{20}\right) \tag{28}$$

By taking the logarithms of both sides, it follows that

$$L_R = -10\log\left[\log^{-1}\frac{-L_A}{10} + \log^{-1}\frac{-L_B}{10} + 2\cos\beta\left(\log^{-1}\frac{-L_A - L_B}{20}\right)\right] \tag{29}$$

A more convenient form of Equation (29) for actual calculation can again be derived in terms of δL and ΔL, as previously suggested.

By multiplying both sides of Equation (27) by

$$\log^{-1}\frac{L_A}{10},$$

we get

$$\log^{-1}\frac{L_A - L_R}{10} = 1 + \log^{-1}\frac{L_A - L_B}{10} + 2\cos\beta\left(\log^{-1}\frac{L_A - L_B}{20}\right) \tag{30}$$

and

$$\log^{-1}\frac{\delta L}{10}=1+\log^{-1}\frac{-\Delta L}{10}+2\cos\beta\left(\log^{-1}\frac{-\Delta L}{20}\right) \quad (31)$$

and

$$\delta L=10\log\left[1+\log^{-1}\frac{-\Delta L}{10}+2\cos\beta\left(\log^{-1}\frac{-\Delta L}{20}\right)\right] \quad (32)$$

Fig. 6 shows curves between δL and ΔL for different values of β. The curve for β equals 10° might be compared with the curve for ΔL in Fig. 4 which, of course, is for $\beta=0$. It will be seen that the maximum divergence of these two curves will occur when $\Delta L=0$ and is equal to .08 db. This divergence decreases as ΔL increases and there is practically no divergence when ΔL is 40 db. In other words, a phase difference of 10 degrees between the voltages E_A and E_B would have a practically negligible effect on the resultant characteristic. The maximum divergence between the curves for $\beta=30°$ and $\beta=0$ is about 0.3 db. for the smaller values of ΔL, and this divergence is practically eliminated when $\Delta L=40$ db. A divergence of but 0.3 db. of the resultant characteristic while not entirely negligible, is of very small effect however. It may be concluded therefore, that phase differences between the values of E_A and E_B of less than 30° would not substantially affect the resultant characteristic. In other words, for phase differences up to about 30° Equations (24) and (32) are practically identical. Phase differences beyond 30° become noticeable, however, and it is necessary to take them into account, Equation (32) giving appreciably different results from those of Equation (24).

It has been shown hereinabove that proportional reductions in the gains of the amplifiers of branches A and B may be made to simulate the effect of a variable artificial line or a variable equalizer, or both. The automatic means for controlling reductions in the gains of the two parallel branches will now be described.

The transformer T_2 is bridged across the circuit at the point b and its secondary winding is connected to the tuned input circuit of a pilot current amplifier H, which selects the pilot current. The pilot current becomes amplified and is then delivered to the unipotential tubes V_5 and V_7 in proportions which may be varied by the potentiometers P_1 and P_2, respectively, which are interposed between the tubes V_5 and V_7 and the amplifier H. The tubes V_5 and V_7 act as rectifiers and therefore the plate current of each of these tubes will increase if the amount of the pilot current increases. Resistances R_1 and R_2 are connected in the plate circuits of the tubes V_5 and V_7, respectively, in series with the corresponding anodes and cathodes, and therefore, the drop in potential across each of the resistances R_1 and R_2 will increase as the magnitude of the pilot current increases. As the potential drops across the resistances R_1 and R_2 increase, the potentials applied to the tubes V_6 and V_8 will correspondingly increase and thereby lower the plate impedance of the latter tubes.

The plate circuit of each of the tubes V_6 and V_8 is connected as a shunt member of an interstage T network interposed between the two tubes comprising the amplifier of each of the branches. In other words, the plate-filament circuit of tube V_6 will form the shunt member of the T network interconnecting tubes V_1 and V_2, and similarly, the plate-filament circuit of tube V_8 will be the shunt member of the T network interposed between the tubes V_3 and V_4. Hence, the gain of the amplifier of each of the two parallel branches of the arrangement shown in Fig. 1 will be dependent upon the plate impedance of the corresponding tube, and therefore, the gain of each branch amplifier will correspond to the magnitude of the received pilot current. This special interstage network for the two parallel branches by which their gain is controlled by associated vacuum tubes, is desirable because it permits a very wide range of gain with a minimum of distortion.

The settings of the potentiometers P_1 and P_2 shown in Fig. 1 are such as to transmit the effect of a larger portion of the pilot current to the rectifying tube V_7 than to the rectifying tube V_5. Accordingly, the shunting effect of the plate circuit of tube V_8 on the interstage network of the B branch will be greater than the effect of the plate circuit of tube V_6 on the interstage network of the A branch. Moreover, the gain of the amplifier of the B branch will be reduced to a greater extent than that of the A branch amplifier. The relative effects upon the two parallel branches will, of course, become greater as the magnitude of the pilot current is increased.

Let it again be assumed that maximum wet weather conditions prevail and that a section of the line C is exposed and requires correction with weather changes as represented by the curves of Fig. 3. It may be also assumed that the potentiometers P_1 and P_2 are set so as to give proper gain reductions in the respective amplifiers of the A and B branches. Under these conditions, as stated hereinabove, the gain must necessarily be zero for all frequencies transmitted between the points b and u. The rectifiers V_5 and V_7 will receive the minimum of pilot current, and the shunting effect of tube V_8 on the interstage network of the B branch will be greater than the shunting effect of the tube V_6 on the interstage network of the A branch. The greater gain reduction of the amplifier of the B branch must, of course, be compensated for elsewhere in the circuit if it be assumed that the amplifiers of the two branches generally have the same gain. In order to provide the overall equality of gains of the two branches, the potentiometer P_4 will be set at a higher point than the potentiometer P_3, and therefore, a greater voltage will be impressed upon the amplifier of the A branch than that which reaches the amplifier of the B branch. If weather conditions improve, the amount of pilot current reaching the rectifiers V_5 and V_7 will increase, thereby causing a corresponding decrease in the gains of the respective branch amplifiers to properly compensate for the change in the attenuation characteristic of the line C. The greater the improvement in weather conditions the greater will be the magnitude of pilot current and the greater the corresponding correction by gain reductions.

If the changes of gain of the amplifiers of the A and B branches, i. e., the reductions in the gains of these amplifiers from the gains under maximum wet weather conditions, be represented as ΔG_A and ΔG_B, respectively, then the functions described hereinabove may be performed if the circuit operates in accordance with the following relations

$$\Delta G_A=-K_1\Delta R \quad (33)$$

and

$$\Delta G_B=-K_2\Delta R \quad (34)$$

In these equations ΔR represents the increase in

db. of the level of the incoming pilot current, and K_1 and K_2 are constants each having a positive value. The ratio

$$\frac{K_1}{K_2}$$

is determined by the position of the characteristic q'' r'' of Fig. 3 which depends upon the type of line facilities, that is, one or another type of cable or open wire. The numerical value of K_1 depends upon the frequency of the pilot current, as does the value of K_2, since the ratio

$$\frac{K_1}{K_2}$$

is fixed. For the specific case numerically given hereinabove with reference to Fig. 3 it was shown that mn rose 10 db. to its new position m'' n'', while op rose 19 db. to its new position o'' p''. These movements in this fixed proportion determine the slope of the characteristic q'' r''. Consequently, the following ratio becomes fixed

$$\frac{K_1}{K_2}=\frac{10}{19} \qquad (35)$$

The values of K_1 and K_2 may be determined from a particular value of the frequency of the pilot current which may be assumed to be, for example, 28 kc. Inasmuch as r'' is 15 db. above r, then when $\Delta G_A=-10$ and $\Delta G_B=-19$, ΔR becomes 15 at a pilot frequency of 28 kc. Substituting these values for ΔG_A and ΔR in Equation (33) it will follow that $K_1=\frac{2}{3}$.

It is to be noted that in the arrangement shown in Fig. 1, the pilot current is picked up at the point b before being transmitted through the two parallel branches. This is done in order that the range of pilot current variation available to control the gain may be as great as possible, it being assumed that it is desired to hold the output at c within limits too narrow to permit satisfactory gain control. Let it be assumed, however, that a range of variation of pilot current output at c sufficient to provide satisfactory gain control may be permitted. Under such conditions there would be a distinct advantage in bridging the pilot current apparatus at the point c in that it would obviate the necessity of establishing an accurate linear relationship between changes in the level of the incoming pilot current and changes in the gain of the amplifiers of the A and B branches in accordance with the Expressions (33) and (34) given hereinabove. By changing the circuit as suggested, it becomes merely necessary that departures in the level of the pilot current above and below its normal value, shall cause corresponding decreases and increases, respectively, in the gains of the amplifiers of the A and B branches so as to maintain the level of the pilot current within the prescribed limits. It will be evident that the narrower the desired range of variation of pilot current output becomes, the more sensitive the gain control circuit must be to changes in pilot current output. The gain control circuit becomes more sensitive as the gain of the amplifier H is increased, accompanied by corresponding changes in the constants of the circuit of the tubes V_5 to V_8 inclusive, in accordance with well known principles.

Even if the pilot current is picked up at the point c of Fig. 1, a linear relationship of the gains in the amplifiers of the two parallel branches must still be properly maintained. This must be obtained mathematically by dividing the Equation (33) by Equation (34) so as to obtain

$$\frac{\Delta G_A}{\Delta G_B}=\frac{K_1}{K_2}.$$

If these relative changes in the gains of the amplifier A and B are maintained, the proper resultant characteristic will be obtained from the voltages transmitted by the two branches.

It will be apparent that the only physical change in the circuit as shown in Fig. 1 required for picking up the pilot current at the point c requires that the leads to the primary winding of the transformer T_2 be bridged across the circuit at point c instead of at b. None of the other circuit elements need be changed.

It is of interest to note that the formulas derived hereinabove for obtaining the resultant of the two component attenuation frequency characteristics, one for the A branch the other for the B branch, are based on the fact that each of these branches is a one-way transmission path. The amplifiers make it impossible for a portion of the output of one branch to be fed back through the opposite branch, or to be reflected back through the same branch from the output transformer, where, with the arrangement shown in Fig. 1, a correct termination of each branch in its characteristic impedance cannot be obtained without the use of a balanced hybrid coil, if the common output at u is correctly terminated. (The same situation regarding termination exists also, of course, at the input transformer T_1.) Such oppositely directed energy is dissipated in the plate circuits of the output tubes of each amplifier, thus preventing echoes and distortion of the resultant characteristic as calculated by the above mentioned formulas. However, it is to be noted that the presence of amplifiers in the A and B branches is not a vital feature of the fundamental principle involved, namely, the production in a circuit of a resultant frequency characteristic of variable slope from two component circuits in parallel whose frequency characteristics are dissimilar and whose gains (or losses) are variable. In other words, the amplifiers could both be removed, any difference in their gains compensated for by the insertion of a resistance network in one branch and the net loss of gain recovered by the insertion of additional amplification in the common portion of the circuit. Such a rearrangement of Fig. 1 might result, for example, in the circuit shown in Fig. 7, in which branch A contains only the so-called artificial line, the gain control network, and a resistance network R representing the difference in gain between the A and B amplifiers. Branch B contains only the equalizer and the gain control network. The gain of the output amplifier in the common portion of the circuit is assumed to be increased to compensate for the removal of the A and B amplifiers. The circuit of Fig. 7 is therefore equivalent to that of Fig. 1 in all respects, except for the fact that in Fig. 7 the A and B branches are not one-way paths. For this reason the resultant characteristic cannot be calculated accurately from the two component characteristics by means of the formulas derived for one-way branches. The derivation of the more involved formulas applicable to this case is not essential to illustrate the principle involved, namely, that the shape of the resultant characteristic, although somewhat different from that obtained with one-way paths, is nevertheless dependent on the shapes of component characteristics, and can

be varied in slope by varying the attenuation in the two branches.

Furthermore, the substitution of a balanced hybrid coil for each of the transformers T_1 and T_3 will eliminate the lack of proper termination of the inputs and outputs of the A and B branches and, depending on how well each coil is balanced, will reduce the feeding back of energy in either branch. The resultant frequency characteristic may thus be made to approach more closely that which would result from the above-mentioned formulas, due to the absence of fed back energy, in spite of the fact that the two branches of the circuit are not one-way transmission paths.

What is claimed is:

1. An arrangement for maintaining the attenuation of all of the transmitted frequencies of a signaling system constant under variable conditions of weather which comprises two coupled parallel paths having different gain frequency characteristics, variable attenuation means included in each path, and means for simultaneously changing the attenuation of said aforementioned attenuation means in accordance with changes in weather conditions.

2. In a signaling system, the combination of two parallel paths, means for simultaneously varying the gains of said paths by different amounts, and means for coupling said paths so as to produce an overall gain frequency characteristic whose gain at different frequencies depends upon the gains of said two paths.

3. In a transmission system, the combination of means for rendering the overall gain frequency characteristic constant under variable weather conditions, said means comprising two parallel paths which are coupled to each other and have different gain-frequency characteristics, and means for simultaneously varying the attenuation of each path.

4. In a transmission system, the combination of means for rendering the overall gain frequency characteristic constant under variable weather conditions, said means comprising two parallel paths which are coupled to each other and have different gain-frequency characteristics, means for simultaneously varying the attenuation of each path, and means for simultaneously changing the attenuation of both paths by different predetermined amounts.

5. The combination of two interconnected parallel paths having different gain frequency characteristics, a one-way amplifier included in each path, and means for simultaneously changing the gains of the two paths by different amounts which are in a fixed proportion.

6. The combination of two interconnected parallel paths having different gain frequency characteristics, and means responsive to weather changes for changing the gains of the two paths simultaneously by different amounts which are in fixed proportions.

7. An arrangement for controlling gain, comprising two interconnected parallel transmission circuits which have gain frequency characteristics of positive and negative slopes, respectively, two rectifying circuits coupled, respectively, to said transmission circuits, means including said rectifiers for controlling the gains of said circuits, and a source of pilot current supplied simultaneously to both rectifying circuits.

8. Gain control apparatus comprising a source of pilot current the amplitude of which varies with weather changes, two parallel rectifiers receiving said pilot current simultaneously, two variable impedance devices connected, respectively, to said rectifiers and controlled thereby, two parallel transmission paths having gain frequency characteristics of positive and negative slopes, respectively, said variable impedance devices being coupled to said transmission paths, respectively, and means for coupling said two transmission paths for obtaining their resultant effect.

9. Gain control apparatus comprising two parallel circuits having different gain frequency characteristics, gain adjusting means for each circuit, two variable impedance devices coupled, respectively, to the gain adjusting means of each circuit, a source of pilot current producing an effect on both of said impedance devices, and means for coupling said parallel circuits so as to change the resultant gain frequency characteristic by a desired amount.

10. The combination of two parallel circuits having different gain frequency characteristics, a pair of amplifiers for each circuit, loss adjusting means coupling the amplifiers of each circuit, a source of pilot current, means responsive to the variations in the level of pilot current to simultaneously change the loss of the adjusting means of both circuits by different amounts which are in fixed proportions, and means to couple said circuits so as to change the resultant gain frequency characteristic by a desired amount.

11. The combination of two parallel circuits having different gain frequency characteristics, means for coupling said circuits so as to obtain a resultant gain frequency characteristics different from that of either of the circuits, and means for simultaneously varying the gains of both circuits by different amounts so as to change the shape of the resultant characteristic.

12. In a signaling system, the combination of a line subject to variable attenuation due to weather changes, two parallel circuits having different gain frequency characteristics which transmit the energy flowing over the line, means for coupling said circuits to said line, and means for simultaneously varying the gains of said circuits by different amounts, whereby the overall gain frequency characteristic of the system will be maintained constant.

13. Gain control apparatus comprising two parallel circuits having different attenuation frequency characteristics, said circuits being coupled to each other, and means for simultaneously changing the attenuations of said circuits by different amounts so as to produce an overall characteristic simulating that of an artificial line.

14. Gain control apparatus for a line transmitting signals the attenuation of which changes with different conditions of weather, comprising two parallel circuits having different attenuation frequency characteristics, said circuits being coupled to each other, and means for simultaneously changing the attenuation of both circuits by different amounts so that the overall characteristic of said circuits will compensate for the changes in attenuation of the line.

15. Gain control apparatus including two parallel circuits which are coupled to each other and have gain frequency characteristics of positive and negative slopes, respectively, and means for reducing the gain of one of said circuits with respect to that of the other so that the resultant gain frequency characteristic of both circuits will resemble the gain frequency characteristic of the circuit having the greater gain.

16. Apparatus for compensating for the loss

in a line transmitting signals during weather changes, comprising two parallel transmission circuits coupled to the line and transmitting the energy received over the line, an artificial line connected in one of said transmission circuits, an equalizer connected in the other of said transmission circuits, a loss adjusting device connected to each of said transmission circuits, a source of pilot current the amplitude of which varies in accordance with the weather changes, two rectifiers both connected in parallel with respect to the source of pilot current, and two variable impedance devices connected respectively to said rectifiers, said variable impedance devices changing in impedance by different amounts with any change in the amplitude of the pilot current, said variable impedance devices being coupled respectively to the two transmission circuits, the loss incurred by the conjoint action of the two transmission circuits compensating for the loss incurred by the line transmitting signals.

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