

T261
X279
X185
X490

Dec. 20, 1938.

J. G. KREER, JR

2,140,915

DISTORTION CORRECTION IN WAVE TRANSMISSION

Filed Aug. 10, 1937

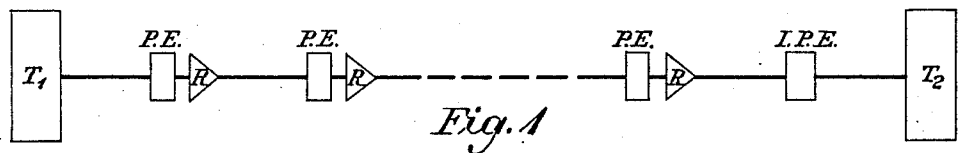


Fig. 1

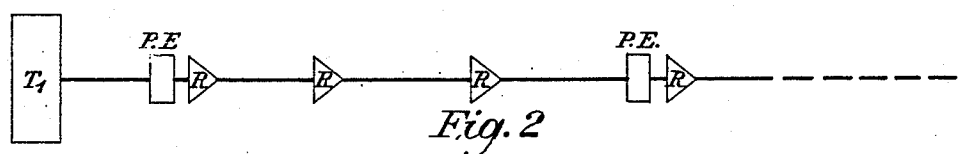


Fig. 2

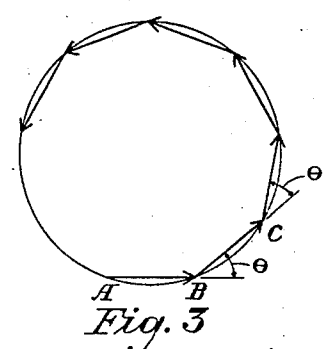


Fig. 3

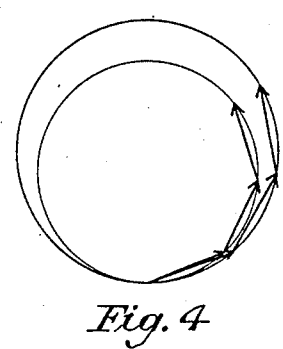


Fig. 4

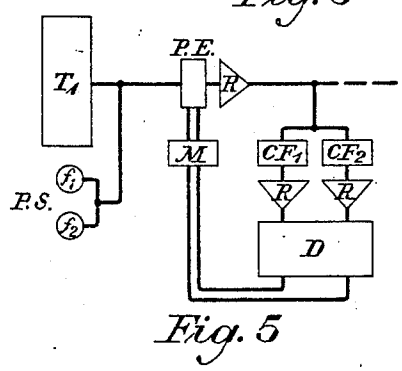


Fig. 5

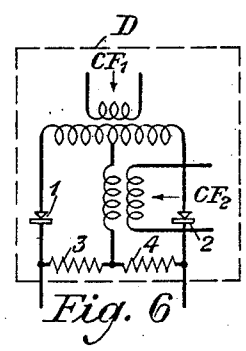


Fig. 6

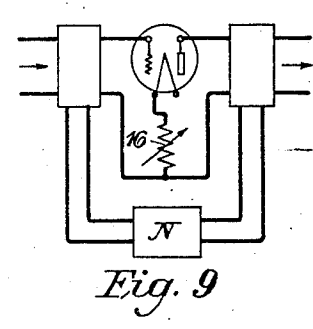


Fig. 9

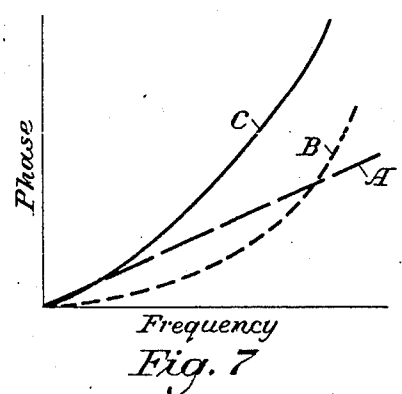


Fig. 7

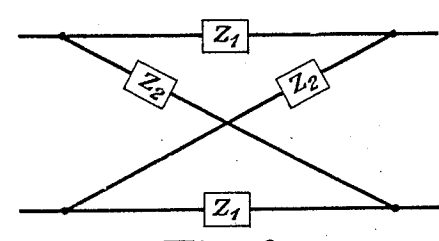


Fig. 8

INVENTOR
J. G. Kreer Jr.
BY H. A. Burgess
ATTORNEY

Patented Dec. 20, 1938

2,140,915

UNITED STATES PATENT OFFICE

2,140,915

DISTORTION CORRECTION IN WAVE
TRANSMISSIONJohn G. Kreer, Jr., Bloomfield, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application August 10, 1937, Serial No. 158,295

18 Claims. (Cl. 178-44)

This invention relates to communication systems and more especially, though not exclusively, to such systems as are identified as broad-band television circuits or as carrier telephone circuits, in which latter case a plurality of channels are used on a single transmission medium for sending out independent messages. One type of circuit of this kind, for example, would be that known as the coaxial conductor. The invention also relates to systems of the nature described, in which a large number of repeaters are connected in tandem.

In spite of the great care which is used in the design and manufacture of such repeaters, there is present in the output of any one repeater a certain small amount of modulation product. While the amount of modulation in any one repeater may be small, if the system comprises a large number of repeaters in tandem, such as several hundred, then the cumulative effect may become substantial. The type of modulation which is especially to be guarded against is that known as interchannel modulation, although intrachannel modulation may also need consideration.

This invention relates to methods and means for maintaining as low as possible at the terminal station the ratio of modulation products to signal intensity.

In a transmission system with repeaters it is the usual practice to make the amplification at each repeater sufficient to just off-set the loss due to attenuation in one repeater section of the cable. Thus, after passing through n repeater sections, the signal strength has been unchanged. The modulation products, however, being introduced additionally at each repeater station tend to increase as the number of repeaters in the line increases. Thus, in one case measured there was a 12-channel telegraph cable with 70 repeaters in tandem 25 miles apart. The modulation voltage at the output was found to be substantially 70 times the modulation voltage of one repeater. The purpose of my invention is a method and means whereby this modulation voltage may be kept to a much lower value.

While the above example related to a telegraph system, substantially the same results would hold for telephone systems. Thus in a recently developed multiplex system, using a special cable, known as the coaxial cable, it is possible to transmit simultaneously a very large number of channels which may extend to the number of 500 to 1,000 telephone channels. In such a system the repeaters may have a spacing of about 5 miles

or less and on a 4,000-mile circuit there would then be involved at least 800 repeaters. If the inter-modulation products follow the law indicated by the experiment referred to above, it will either become excessive in amount or will require extraordinarily careful design of repeaters to keep down the modulation generated in any one repeater.

For a better understanding of the invention one may consider first a single amplifier. For an ideal amplifier (which is a physical impossibility), it is assumed that the output is a faithful copy or replica of the input voltage except as enlarged and except as it may be delayed. Due to unavoidable non-linearity, harmonics and other undesired products of modulation are present and will be represented as voltage variations in the output not present in the input but still in the signal frequency band. From the standpoint of how these products of modulation combine as a function of the number of repeaters, it will be necessary to distinguish and consider separately the even and the odd order products of modulation. For the purposes of this discussion, it will be sufficient to consider only the second order products and the third order products of modulation.

Consider a resistance line of loss L followed by a flat gain amplifier of gain G , and consider a group of such identical units in tandem. Let X be the input at the transmitting end of the line which attenuates to x in passing through the first section of line so that the input at the first repeater is represented by x . The output of the amplifier may be represented by

$$X + k_2x^2 + k_3x^3 + \dots \quad (1)$$

It will be observed that poling or reversing the input of the repeater does not change k_2x^2 but does reverse the other two terms given above. The input of this amplifier is not poled.

Passing to the second amplifier, its input is

$$x + (k_2x^2 + k_3x^3 + \dots)e^{-L} \quad (2)$$

where L is in nepiers. The output of the second amplifier is the amplified output due to the term x , namely, $X + k_2x^2 + k_3x^3 + \dots$ plus the distortion introduced by the second amplifier which is $(k_2x^2 + k_3x^3 + \dots)$. It will now be observed that by poling the input to the second amplifier the second order terms cancel each other in the output of the amplifier but the third order terms do not, so that the output of the second amplifier is $-X - 2k_3x^3 - \dots$. Thus, in the absence of phase shift in either line or amplifier, and in the

presence of flat loss and flat gain with frequency, if every other amplifier is poled then with an even number of amplifiers the even order modulation products are theoretically zero and the odd order modulation voltage products are equal in amplitude to those of a single amplifier multiplied by the number of amplifiers. Thus, the modulation voltage products for these terms add up arithmetically and the modulation power output is given by $P=n^2E^2$ where E is the modulation voltage set up by one repeater.

If the resistance line in the previous example is replaced by a telephone cable for which the velocity of transmission of a wave is the same for all frequencies, then there will be a time delay as one passes over a repeater cable section but the wave shape at the input of one repeater is identically the same as the wave shape at the output of the previous repeater. Such a condition is quite closely approximated over a wide frequency band in the so-called coaxial cable and it will be apparent from what has been said heretofore that by suitable poling at the successive repeaters it is possible to balance out even order terms but that the odd order modulation voltage terms are those of a single amplifier multiplied by the number of amplifiers. For such an ideal transmission medium, the actual phase shift, expressed in radians, as one passes over a repeater section is proportional to the frequency and would be represented by a phase frequency characteristic which is a straight line passing through zero, as indicated by curve A of Fig. 7.

If the straight line phase relationship stipulated above is not satisfied then the rule previously cited is no longer valid. Assume, for example, that by additional phase retardation at certain points on the transmission line, such as at the input of each repeater, the phase frequency characteristic departs from the previous straight line relationship. Assume, also, that X is a sine wave. The output of the first amplifier of the string is not affected by these changes, neither is the signal input to the second amplifier to the extent that the harmonics generated in the second amplifier depend only upon the fundamental applied. Added to them, however, are the amplified harmonics from the first amplifier which by comparison to the original condition are retarded in phase by the input equalizer of the second amplifier. Assuming even numbered amplifiers are poled, if the amplified second harmonic as produced in the first amplifier originally opposed or canceled the second harmonic produced in the second amplifier, then with the added phase retardation to the frequency $2f$ over that to the frequency f in the input equalizer this opposing action or balance is impaired to an extent depending upon the amount of phase increment introduced. In a similar way, when considering a third order product such as one of frequency $3f$, if without the extra phase shift in the input equalizer to $3f$ the effect of the $3f$ component from the first amplifier was to add precisely in phase with the $3f$ component produced by the second amplifier, then with the extra phase shift the vector sum of the two is less. Similar effects take place at succeeding amplifiers.

As pointed out above, the invention is especially but not exclusively applicable to a transmission system in which a wide frequency band is divided into a large number of signal channels. In this case the width of any one channel band is usually small compared to the total signaling band but

repeaters are used in common by all or a large number of the channels. The non-linearity of the repeaters will give rise to sum and difference frequencies commonly called modulation frequencies, or modulation products as the term has been used above. Any one modulation frequency may be obtained in numerous ways. Thus, for the summation frequency $f_3=f_1+f_2$, f_1 and f_2 may take on a large variety of values but a particular pair of values may be spoken of as one modulation source for the frequency f_3 and there will be many such sources in the broad band, giving rise to a particular modulation frequency f_3 in any specific channel. Furthermore, while in any one channel the modulation frequencies will be distributed over all frequencies in that band, the band is relatively so narrow that for most considerations it is feasible to treat all the modulation frequencies in that channel band as being of one frequency.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which:

Fig. 1 shows a transmission line with a large number of repeaters connected in tandem, each repeater being provided with a phase equalizing or phase shifting device the characteristic of which will be described later;

Fig. 2 shows a modification of Fig. 1;

Figs. 3 and 4 are diagrams to assist in the explanation of my invention;

Figs. 5 and 6 relate to means to compensate for certain variations;

Fig. 7 is a diagram showing certain phase frequency characteristics applicable to an understanding of my invention;

Fig. 8 shows a physical form which the phase equalizers of Fig. 1 may take on; and

Fig. 9 relates to certain compensating arrangements.

Referring more particularly to Fig. 1, there is shown a transmitting station T_1 and a receiving station T_2 joined by a transmission line, such as a coaxial cable. In this line there are numerous repeaters R in tandem and in accordance with well established practice, the gain of each repeater is set at such a value as to just compensate for the loss in the previous section of cable so that at the end of the line the intensity of the signal is substantially the same as at the transmitting end. In each repeater section there is a phase equalizer PE, here shown at the repeater input, which serves the function of introducing a relative phase shift among the currents of different frequency in accordance with a plan to be shown later. For the purpose of simplicity it will be assumed that all repeater sections (including the phase equalizer) are identical. Let the modulation voltage generated in one repeater be E, this modulation product arising from certain signal frequencies. When these signal and modulation voltages have arrived at the input of the next repeater, having passed through a cable section and a phase equalizer, the phase of the modulation product voltage with respect to its generating signal voltages will have been modified. The signal passing through the second repeater will give rise to another element of modulation voltage of value E bearing the same phase relationship to the generating signal voltages as existed between the first modulation product and the signal at the output of the first repeater and this second generated modulation product will be out of phase with that which arrived from the first repeater

and was amplified in the second repeater. This phase difference will be indicated by θ and will be assumed the same for each section. On this basis the resulting modulation voltage at the end of n repeaters will be

$$M(n) = E[1 + e^{j\theta} + e^{j2\theta} + \dots + e^{j(n-1)\theta}] \quad (1)$$

This is a geometric series which is readily summed up to be:

$$M(n) = E \frac{1 - e^{jn\theta}}{1 - e^{j\theta}} = E \frac{1 - \cos n\theta - j \sin n\theta}{1 - \cos \theta - j \sin \theta} \quad (2)$$

At the receiving terminal the particular phase of the modulation product is not of importance but the magnitude is; and the magnitude of the modulation voltage is readily obtained from Equation 2 as

$$|M(n)| = |E| \sqrt{\frac{(1 - \cos n\theta)^2 + \sin^2 n\theta}{(1 - \cos \theta)^2 + \sin^2 \theta}} = |E| \sqrt{\frac{1 - \cos n\theta}{1 - \cos \theta}} \quad (3)$$

Simplification of Equation 3 yields

$$|M(n)| = \frac{E \sin \frac{n\theta}{2}}{\sin \frac{\theta}{2}} \quad (4)$$

and it is seen that this has a maximum value for

$$\frac{n\theta}{2} = \frac{\pi}{2}$$

Thus the maximum modulation, without regard to the number of repeaters, is given by

$$|M|_{\max} = \left| \frac{E}{\sin \frac{\theta}{2}} \right| \quad (5)$$

and for some values of n will be less.

The value of the modulation voltage generated in one repeater from a certain modulation source has been represented by E . The total modulation product at the end of the line due to this source will of course be greater. If the amount of modulation voltage from that source permitted for the whole system is E_1 at the terminal station then the system will be operative regardless of the number of repeaters if we intentionally introduce phase distortion at each repeater of such nature as to make the modulation phase increment θ satisfy the relationship

$$\frac{E}{\sin \frac{\theta}{2}} \leq E_1 \text{ or } \sin \frac{\theta}{2} \geq \frac{E}{E_1} \quad (6)$$

The phase increment for a single product is readily determined from the phase-versus-frequency characteristic of the system and the specification of a form of the product thus: Let the frequency of the modulation product be $uf_1 + vf_2$, where $u+v$ is the order of modulation, and let the phase shift per span be $\varphi(f)$. Then it can be shown that

$$\theta = \varphi(uf_1 + vf_2) - u\varphi(f_1) - v\varphi(f_2) \quad (7)$$

If now there are several sources instead of one, they will, in general, be non-coherent. The combination will, therefore, yield a total modulation power output equal to the sum of the power outputs of the individual sources, and thus the modulation voltage will be given by

$$|M(m, n)| = E \sqrt{\sum_{r=1}^{r=m} \frac{\sin^2 \frac{n}{2} \theta_r}{\sin^2 \frac{1}{2} \theta_r}} \quad (8)$$

where m is the number of sources, n the number of repeaters and E is assumed to be the same for all modulation sources. Now if the θ_r 's are incommensurable, the maximum possible value of M will occur for that n which makes all the $n\theta_r = k\pi$ and in that case

$$|M(n)| = E \sqrt{\sum_{r=1}^{r=m} \frac{1}{\sin^2 \frac{1}{2} \theta_r}} \quad (9)$$

If the θ_r 's are commensurable, then we may find there is no value of M which can satisfy this condition and the actual maximum of modulation product will be less than this power bound. However, Equation 9 still gives an upper bound of the modulation product. By writing E_r for E in Equation 9, the limit of total modulation voltage M is found for a given signal channel where E_r is the modulation voltage in that channel generated between two adjacent intermediate points due to any one source for any one frequency and θ_r is the phase displacement between that voltage and the analogous voltage arriving at the first of the said two intermediate points. Thus,

$$|M| \leq \sqrt{\sum \frac{E_r^2}{\sin^2 \frac{\theta_r}{2}}}$$

It is thus seen that we can place an upper limit upon the amount of modulation interference voltage which may occur in a system by introducing, if necessary, additional and enough phase distortion by means of a suitable network at regular intervals, preferably at each repeater, so that if E is the generated voltage for one source in one repeater and E_1 the permissible modulation for the complete system then

$$\frac{E_1}{E} = \sqrt{\sum_{r=1}^{r=m} \frac{1}{\sin^2 \frac{1}{2} \theta_r}} \quad (10)$$

Furthermore, if this phase distortion is sufficient to be objectionable from a transmission standpoint, it may be equalized at either end-of-the system or at any point without in any way affecting the modulation.

The analysis given above may be made more clear by the graphical representation of Fig. 3. If the vector AB represents the modulation voltage from a particular modulation source and at the output of the first repeater, then there will be an equal modulation product generated in the second repeater but because of the phase distortion present between the output of the first and the output of the second repeater this second vector will be out of phase with the first one by the angle θ and would be represented in Fig. 3 by the vector BC. The resultant of these two vectors obviously is the line joining the points A and C. If additional repeaters are considered, then the vector diagram is obtained by continuing the drawing of the vectors each with a phase increment θ and it will be seen that the maximum value which the modulation voltage can attain is that given by the diameter of the circumscribing circle, this circle being the one identified as passing through three such points as A, B and C. The condition for maximum value of the modulation product in the situation described heretofore corresponds to the diameter of the circle. The possibility is envisaged of reducing this actual modulation product to a value substantially below that corresponding to the diameter of the circle, but the insignificant point is that it can be kept to a

specified low value regardless of the number of repeaters. More specifically it will be seen that in such a system a particular modulation product, as a function of the number of repeaters, alternately reaches maximum and minimum values with increasing numbers of repeaters, changing in a cyclical manner. It will be noted that the diameter of the circle is given by

$$\frac{E}{\sin \frac{\theta}{2}}$$

and to the extent that θ can be controlled the maximum modulation voltage can be controlled.

The question now arises as to what phase characteristic should be given to a repeater section in order that the results indicated by the analysis shall be attainable. The question is complicated by the fact that in any one channel any and all the frequencies available for the band width of that channel will be represented at one time or another in the signal frequencies and that superposed on these signal frequencies are the same frequencies appearing as modulation frequencies from one source or another, such as inter-channel modulation.

I find that the conditions given above, namely, that the maximum modulation present shall not exceed a value corresponding to the circle of Fig. 3, can be obtained with considerable latitude as to the phase frequency characteristic of the repeater section (including the phase equalizer), but of the numerous ones possible the one shown by curve C of Fig. 7 I find to be simple in form and possible of realization. It is especially effective in case the second order harmonics are important. The curve C of Fig. 7 is the sum of the curves A and B. Curve A represents the phase frequency characteristic of the line of the repeater section, which in the case of some lines such as a coaxial cable may be substantially a straight line passing through the origin. Curve B represents the phase frequency characteristic of the phase equalizer which is so designed that curve C is one of a family of parabolas each of which passes through the origin. If curve A is a straight line then curve B is itself a parabola with the apex at the origin. The curve C being parabolic may be represented by the equation

$$\varphi(f) = k_1 f + k_2 f^2$$

Having determined the desired form of phase frequency characteristic as represented by such a curve as that of Fig. 7, it now becomes feasible to design a network which taken alone or in combination with the cable section will give that particular phase frequency characteristic. The matter of design of such a network does not constitute a part of my invention but the procedure for such design is set forth in the literature in such articles as, for example, that of Zobel, in the Bell System Technical Journal, vol. 7, page 488, or patent to Zobel 1,603,305 of October 19, 1926. Fig. 8 illustrates one type of network commonly called an "all-pass" structure, which has great flexibility so far as phase frequency characteristic is concerned. The impedances Z_1 and Z_2 in this network may consist of inductances or capacitances or both and each impedance may be a simple unit or a complex one. By proper choice of the capacities and inductances assigned to each of the impedances of the network, phase frequency characteristics of a wide range may be obtained.

In the above considerations it has been assumed that all repeater spans are identical, both as to

the amount of modulation generated and as to the phase increment of the product. This condition will, of course, never be realized in practice since, in general, some of the phase increment will be contributed by the line and hence will vary with the length of the span. Also, the amount of modulation generated will vary with variations in vacuum tubes, circuit elements, etc. However, the extent of the variation will be limited due to the fact that all possible lengths of span are not used but only those between certain limits and by the fact that inspection of repeaters will reject any in which the modulation exceeds a certain amount. The effect of the variations can be determined to a certain extent by a simple geometrical method indicated in Fig. 4 and thus the tolerable limits of variation may be determined. If the repeater sections are identically the same in every respect then the vector diagram of Fig. 3 is appropriate. If we consider the case of variable E and θ , we may construct the circles corresponding to the maximum value of E with the minimum value of θ and the minimum value of E with the maximum value of θ . Such vector diagrams with their circumscribing circles are represented in Fig. 4. The actual resultant will not, in general, lie far outside the region between the two circles regardless of the distribution of the θ 's and the E 's.

In the event that the phase shift for one section, because of temperature or humidity variations as they effect the cable or because of aging of the repeaters, is larger than is desired, such variations may render it desirable to make the phase equalizer at the input of a repeater or elsewhere variable and controlled in such a manner as to compensate for the variations arising otherwise in the repeater sections. A large variety of circuit arrangements may be used for this purpose and one such arrangement is shown in Fig. 5 this being for illustrative purposes only. In Fig. 5 there is shown at the beginning of one repeater section a pilot signal source which may consist of a generator of two frequencies f_1 and f_2 , these being chosen as typical frequencies for which compensation should be made. Signals of these frequencies are impressed on the repeater section and are shown as being taken off at the output of the repeater R by sharply selective filters such as crystal filters CF_1 and CF_2 . These two frequencies may now be amplified and passed through some suitable detecting device D which will have an output the phase and amplitude of which are dependent on the phase relationship between f_1 and f_2 and they may be used to control some device such as a motor M to change the phase equalizer by an amount sufficient to compensate for the variation which has taken place in the repeater section. The motor, for example, may be used to control a variable air condenser.

While the detecting device D may take on a large variety of forms, one such form is shown in Fig. 6 for illustrative purposes. Here the output of the filter CF_1 is impressed by means of a transformer on a circuit comprising two rectifiers 1 and 2, such as copper-oxide rectifiers. The circuit also includes an impedance such as the resistances 3 and 4. Bridged across this particular network is a transformer the primary of which is supplied from the output of the filter CF_2 . The direction of flow of the rectified current in the resistance will be in the one direction or the other depending upon whether there has been a shift in phase in one direction or

2,140,915

5

the other of one of the pilot signals with respect to the other.

Again, if we find that the repeaters are not all identical even with such compensation as just described, we may consider the total modulation as being made up of two parts, a systematic part equal to the average value and a random deviation from that value. The systematic part will add up in the manner already described. The random deviations will have a most probable value equal to the square root of the number of repeaters times the standard deviation and will have a maximum value equal to the number of repeaters times the maximum possible deviation. The resultant of these deviations must add vectorially to the resultant of the systematic portion which has already been discussed. If the number of repeaters is large this contribution of the deviations may conceivably be fairly large compared to the systematic portion, and it is, therefore, desirable to reduce as much as possible the deviations of the modulation generated in the repeaters. Supplemental then to such other compensations as may be introduced, such reduction may be accomplished by the use of feedback amplifiers in which the gain of the amplifier tube is varied, either manually or automatically, in such a way as to maintain a constant modulation coefficient from repeater to repeater. Fig. 9 shows one embodiment of this idea. Here a typical repeater section with a stabilizing feedback circuit N is indicated. In series with the cathode is shown a variable resistance 16 common to both the input and output circuits of the repeater and serving as a local feedback circuit. By varying this resistance, and thus the gain of the repeater, its characteristic may be altered in such a way, manually or automatically, as to maintain a constant modulation coefficient for the repeater section.

While the invention has been described in terms of the circuit of Fig. 1 it is to be understood that many variations may be introduced, thus, whereas in Fig. 1 a phase equalizer is shown in front of each repeater one may find it desirable to use a phase equalizer for a group of repeaters such as shown in Fig. 2. Also the compensations referred to above may be made at each repeater or at each phase equalizer or in connection with groups of these. The decision as to the frequency of spacing of phase equalizers or of compensating means will depend upon the magnitude of the effects desired or the effects to be compensated for.

What is claimed is:

1. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, the method of reducing the ratio of modulation products to signal intensity which consists in introducing phase distortion at a plurality of points, the phase distortion being of such character as to produce similar angular shift, in the same direction, of the modulation voltages produced in successive repeaters and to keep the maximum resultant modulation voltage for any one frequency below a definite value regardless of the number of repeaters.

2. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, the method of reducing the ratio of modulation products to signal intensity which consists in introducing phase distortion at a plurality of points, the phase distortion being of such a character that the modulation voltage from repeater to repeater progressively rotates in the

same angular direction and the resultant value of the modulation voltage changes in a substantially cyclical manner.

3. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, the method of reducing the ratio of modulation products to signal intensity which consists in introducing phase distortion at a plurality of points, the phase distortion being of such character as to keep the maximum resultant modulation voltage for any one frequency below a definite value given by

$$M = \frac{E}{\sin \frac{\theta}{2}}$$

where E is the modulation voltage generated in one repeater and θ is the phase distortion for that frequency between two of said points adjacent to each other.

4. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, each giving rise to a modulation voltage which for any frequency from any one modulation source is given by E, the method of keeping the modulation voltage for the line at that frequency below a predetermined value E_1 in excess of E which consists in introducing in connection with each repeater section a phase frequency distortion θ for that frequency of such value that

$$\sin \frac{\theta}{2}$$

is greater than

$$\frac{E}{E_1}$$

5. The combination of claim 4 characterized by the fact that the phase distortion is introduced at each repeater.

6. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem and adapted for a plurality of signal channels, the method of reducing the ratio of modulation products to signal intensity which consists in introducing phase frequency distortion at a plurality of uniformly spaced intermediate points, the phase frequency distortion being of such character that the total modulation voltage M in a given signal channel is equal to or less than

$$\sqrt{2 \frac{E_r^2}{\sin^2 \frac{\theta_r}{2}}}$$

where E_r is the modulation voltage in that channel generated between two adjacent intermediate points due to any one source for any one frequency and θ_r is the phase displacement between that voltage and the analogous voltage arriving at the first of the said two intermediate points.

7. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, each repeater giving rise to modulation voltages, phase distorting means at a plurality of points substantially equally spaced electrically and dividing the line into equal sections, the phase frequency characteristic of the distorting means with that of its section being such that the modulation voltage at any one frequency generated in one section will be displaced in phase by the amount θ with respect to the same modulation voltage arriving at that section, where θ is given by

$$\frac{E}{E_1} = \sin \frac{\theta}{2}$$

E is the modulation voltage generated in one section and E_1 is the maximum modulation voltage at that frequency permitted in the transmission line.

5 8. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, each repeater giving rise to modulation voltages, phase distorting means at a plurality of points substantially equally spaced electrically, dividing the line into equal sections, the
10 phase frequency characteristic of the distorting means with that of its section being a parabola.

9. In a signal transmission system comprising a transmission line with a plurality of repeaters
15 in tandem, each repeater giving rise to modulation voltages, phase distorting means at a plurality of points equally spaced electrically, dividing the line into equal sections, the phase frequency characteristic of the distorting means with
20 that of its section being one of a family of parabolas passing through the origin of the phase frequency diagram for the section.

10. The combination of claim 8 characterized by the fact that one of the phase distorting means
25 is placed in each repeater section.

11. The combination of claim 8 characterized by the fact that one of the phase distorting means
is introduced at each repeater.

12. In a signal transmission system comprising
30 a transmission line with a plurality of repeaters in tandem, giving rise to modulation voltages, means providing that the total modulation voltage for the line at a given frequency shall not
35 exceed a predetermined value E_1 , means comprising a plurality of phase equalizers equally spaced and dividing the line into a plurality of equal sections in each of which the generated modulation voltage is E, the phase equalizer being of
40 such character as to introduce a phase shift θ between the modulation voltage generated in one section and the analogous modulation voltage ar-

iving from the previous section equal to or greater than that given by

$$\sin \frac{\theta}{2} \geq \frac{E}{E_1}$$

13. The combination of claim 12 characterized
5 by the fact that the phase equalizers are placed at each repeater.

14. The combination of claim 8 characterized
10 by the fact that there is a phase correcting network at one point in the line to compensate for the plurality of phase distortions given to the desired signal by the plurality of phase distorters.

15. The combination of claim 12 characterized
15 by the fact that there is a phase correcting network at one point in the line to compensate for the plurality of phase distortions given to the desired signal by the plurality of phase equalizers.

16. The combination of claim 12 combined with
20 means at a repeater station to compensate for uncontrolled variations in phase frequency relationship of a section of the transmission line.

17. The combination of claim 12 combined with
25 means at a repeater station to automatically compensate for uncontrolled variations in the modulation generated in the repeater section.

18. In a signal transmission system comprising
30 a transmission line with a plurality of repeaters in tandem each giving rise to a modulation voltage of a given frequency of a value E_r from a plurality of modulation sources, the method of keeping the modulation voltage at that frequency for the transmission line below a predetermined
35 value E_1 which consists in introducing in connection with each repeater section a phase frequency distortion θ for that frequency of such value that

$$\sqrt{\frac{\sum E_r^2}{\sin^2 \frac{1}{2}\theta_r}}$$

is less than E_1 .

JOHN G. KREER, JR.