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DISTORTION CORRECTION IN WAVE TRANSMISSION

Filed Aug. 10, 1937

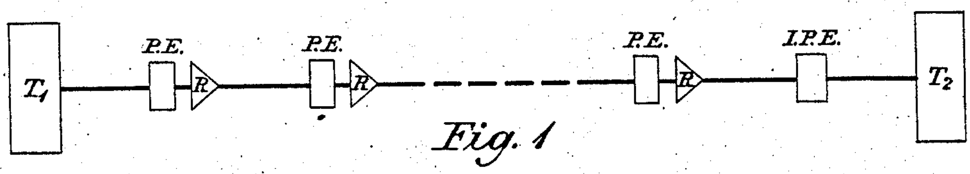

Fig. 1

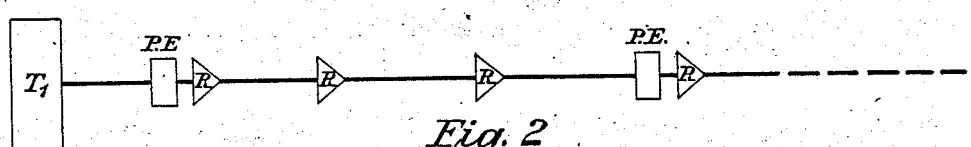

Fig. 2

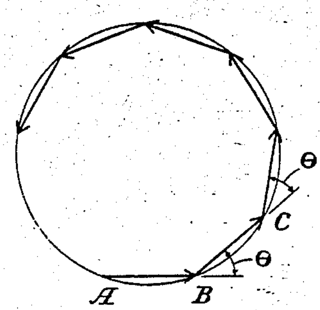

Fig. 3

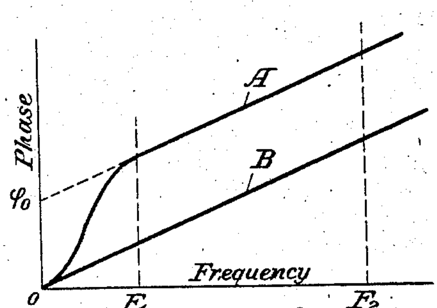

Fig. 4

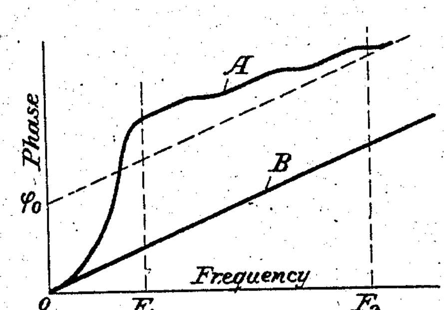

Fig. 5

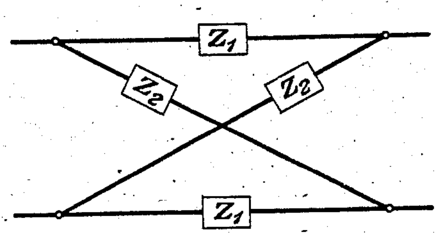

Fig. 6

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DISTORTION CORRECTION IN WAVE TRANSMISSION

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Application August 10, 1937, Serial No. 158,296

8 Claims. (Cl. 178—44)

This invention relates to communication systems and more especially, though not exclusively, to such systems as are identified as carrier telephone circuits, in which a plurality of channels are used on a single transmission medium for the transmission of 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, such as several hundreds of repeaters in tandem, then the cumulative effect may become substantial. One of the types of modulation which is particularly to be guarded against is that known as interchannel modulation. Another type is that which may be identified as intrachannel modulation.

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.

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. Any one modulation frequency may be obtained in numerous ways. Thus for the summation frequency $f_3=f_1+f_2$ the components 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 specified channel.

In a copending application of Kreer, Serial No. 158,295, filed of even date herewith, there is discussed the question of the manner in which modulation products accumulate in such a system as described. It is there pointed out that if each repeater section comprises a cable of flat loss and a repeater of flat gain, and if there is no relative phase shift of the different frequency components as one goes through a section of cable, then it is possible by proper poling of the repeaters to cause the even-power modulation terms to balance out, but that the odd-power terms will add up arithmetically, so that if E is the modulation voltage generated in each repeater and there are n repeaters, then the modulation voltage at the end of the line will be nE for odd-number terms and the modulation power output will be proportional to n^2E^2, whereas the signal intensity will be the same at the receiving end as at the transmitting end. It was pointed out in that application that if a relative phase shift among the components of different frequency is introduced in each repeater section, either because of the phase frequency characteristic of the cable span or because of intentionally introduced phase distortion, that the balancing out of the even-power terms will no longer be present and also that the odd-power terms no longer add up arithmetically.

Also in that application it was pointed out that by a suitable relative phase shift θ between the modulation product generated within a repeater section from given fundamental frequencies and the similar modulation product arriving from the previous section it is possible to cause the modulation voltage generated in the respective repeater sections to add up vectorially in a systematic manner and in such a way as to cause the resultant modulation voltage at the end of the line to be less than that envisaged heretofore.

It was also pointed out that if E is the modulation voltage generated in one repeater from a certain modulation source and if the amount of voltage modulation from that source permitted for the whole system is E_1 at the output, that the actual modulation voltage will not exceed E_1 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 at that frequency satisfy the relation

$$\sin\frac{\theta}{2}\geq\frac{E}{E_1} \qquad (1)$$

The matter of specifying the most useful form of phase frequency distortion in order to attain the desired results constitutes the chief purpose of this invention, which 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 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;

Fig. 3 is a vector diagram to assist in the explanation of our invention;

Figs. 4 and 5 show phase frequency characteristics of the phase equalizers which we find it desirable to give to each repeater section; and

Fig. 6 represents one form which the phase equalizer may take.

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. In accordance with well-established practice, the gain of each repeater is set at such a value as to just compensate for loss in the previous section of the cable, so that at the end of the line the intensity of the signal is substantially the same as at the transmitting end. At each repeater point, such as at the input of the repeater or at the output of the repeater, or at certain specified points along the cable, there are introduced phase equalizers PE, here shown at the input of each repeater, which serve the function of introducing a relative phase shift among the currents of different frequency in accordance with the plan to be shown herein. In this invention it is desirable that the sections including the phase equalizer be as nearly identical as possible.

The desired condition for the phase displacement, as it refers to a single modulation frequency arising from a given modulation source, has been given above. In general, however, as already pointed out, there will be a number of sources which will give rise to the same modulation frequency lying in the channel which is under consideration. In that case the total modulation product will be given by

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

and the condition to insure that this value shall not, at the end of the line, rise above the permissible modulation voltage is given by the relation

$$\frac{E_1}{E}=\sqrt{\sum_{r=1}^{r=m}\frac{1}{\sin^2\frac{1}{2}\theta_r}} \qquad (3)$$

The analysis given above may be made more clear by the graphical representation of Fig. 3. If the vector AB represents the modulation voltage generated in the first repeater from a particular modulation source as it appears at the output of the second 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 the resultant modulation voltage is given by a vector drawn from the beginning of the first vector to the end of the last vector. It will be seen that the maximum value which the modulation voltage can attain is that given by the diameter of a circumscribing circle, this circle being the one identified as passing through the three points A, B and C. The condition for maximum value of the modulation product in the situation described analytically heretofore corresponds to the diameter of the circle and the possibility is immediately envisaged of reducing this actual modulation product to a value substantially below that corresponding to the diameter of the circle. 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 and no matter what the number of repeaters, will not rise above the value corresponding to the diameter of the circle.

The phase increment θ for a single product is readily determined from the phase frequency characteristic of the system and the specification of the form of the modulation product. Thus, let the 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 readily be shown that

$$\theta=\varphi(uf_1+vf_2)-u\varphi(f_1)-v\varphi(f_2) \qquad (4)$$

This expression relates to any phase frequency characteristic but we have found that a phase characteristic such as represented by curve A of Fig. 4 is a particularly suitable one for the purpose at hand. In this Fig. 4 it will be noted that the phase shift over the transmission band is related to the frequency by means of a straight line, which extrapolated to zero frequency intersects at a phase shift different from zero, say φ_0. Under these conditions any second order modulation product generated by two frequencies within the transmitted band and itself lying within the transmitted band will have a phase increment equal to $\pm\varphi_0$. Likewise, any third order modulation product, except the positive third order differences, will have a phase increment of $\pm2\varphi_0$. This can be readily demonstrated by an illustration. Consider, for example, a third order modulation frequency of $2f_1+f_2$, where f_1 and f_2 are the frequency sources which give rise to this modulation frequency. The equation for the phase shift frequency characteristic of curve A is given by $\varphi=\varphi_0+kf$. On substitution of $f=2f_1+f_2$ it will be noted that $\theta=-2\varphi_0$. Thus, any third order modulation of the form $2f_1+f_2$ from any two sources will have the same relative shift as one moves from one repeater to another. So also for modulation products of the form $3f_1$. Second order modulation frequencies will have a constant phase shift per repeater section of $\theta=-\varphi_0$.

In general, the importance of any modulation product decreases as the order of the modulation product increases. Also, so far as the third order modulation products are concerned, all of these call for the same value of θ with the exception of the positive third order differences. Inasmuch as these latter constitute a relatively small portion of the total modulation products they may usually be ignored. If, on the other hand, they should become of importance they may also be largely reduced by causing the phase frequency characteristic of the section to depart from the straight line relationship of curve A in Fig. 4. Such departure, for example, is shown in Fig. 5, in which the characteristic is given a sinuosity. This sinuosity may take on any form so long as it fulfills the condition that a straight line drawn through any three points of the characteristic shall not have an intercept numerically smaller than φ_0.

Ordinarily it would be difficult to obtain a phase frequency characteristic in accordance with curve A of Fig. 4 extending down to zero frequency. As one approaches zero frequency, the characteristic itself would approach zero in some such manner as indicated by the full line of curve A. The frequency F_1, below which the straight line characteristic is not maintained, can by suitable design be made quite low and the frequency band from 0 to F_1 would not be used for the type of signaling in mind. In practice this is not a serious limitation for there are other reasons which make it desirable to relegate this lower frequency band to other uses.

It is of importance for the best results in the use of our invention that the successive equalizer sections shall be as nearly identical as possible and that they shall be maintained in this condition during operation. Here an equalizer section is taken to mean the line between two adjacent phase equalizers plus any and all attachments thereto. In practice, the ideal condition of perfect identity and constancy cannot be reached for there will be variations in the sections due to numerous causes such as temperature or humidity changes or aging of the tubes. If these become of significance, it is desirable to introduce compensating means, preferably automatic. Such compensation means have been described in the application of Kreer cited above, and it is contemplated that these would be introduced to such extent as seems desirable in connection with the exercise of this invention.

Having determined the desired form of phase frequency characteristic as represented by curve A of Fig. 4 and represented further by $\varphi=\varphi_0+kf$, it then becomes feasible to design a network which, taken alone or in combination with the equalizer section, will give the desired phase frequency characteristic. The matter of design of such a network does not constitute a part of our invention but the procedure for such design is set forth in the literature in such articles as, for example, by Zobel in the Bell System Technical Journal, volume 7, page 488, or patent to Zobel 1,603,305 of October 19, 1926. Fig. 6 illustrates one type of network commonly called an "all-pass" structure, which has great flexibility so far as phrase frequency characteristic is concerned. The impedance Z_1 and Z_2 in this network may consist of inductances or capacities 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, a phase frequency characteristic of the type desired may be obtained.

Having determined the value of θ to keep M equal to or less than E_1, which is specified by engineering practice, one finds the intercept φ_0 by means of the relationship $\theta=\pm\varphi_0$ for the permissible second order modulation, and $\theta=\pm2\varphi_0$ for third order products and so on. Since θ here is larger than for the second order products, it means that if the value of E is the same as for the second order effects, the vector circle is smaller in diameter. Thus third order modulation products are minimized even more effectively than the second order products.

The slope of curve A of Fig. 4 is given by the constant k. Usually the slope of this curve will not be far different from that of the curve B, which is that of a transmission line section without the equalizer.

What is claimed is:

1. In a signal transmission system comprising a transmission line adapted for a wide band of frequencies, a plurality of repeaters in tandem in said line, means for increasing the ratio of signal to modulation products for the system comprising phase equalizing means introduced in the line dividing the line into electrically equal sections, the phase frequency characteristic of each equalizer plus its section being such that a straight line drawn through any three points on the portion of the characteristic lying within the useful band has a phase intercept other than zero at zero frequency.

2. In a signal transmission system comprising a transmission line adapted for a plurality of channels, a plurality of repeaters in tandem in said line so spaced that the repeater sections are electrically equal, means for increasing the ratio of signal to modulation products for the system comprising a phase equalizer introduced in each repeater section, the phase frequency characteristic of the equalizer being such that a straight line drawn through any three points on the portion of the resultant characteristic of line section plus equalizer within the useful band has a phase intercept at zero frequency at least as great as the phase intercept at zero frequency of a phase characteristic which differs from a fixed phase shift by an amount proportional to the frequency throughout the useful band.

3. The combination of claim 1 characterized by the fact that the phase frequency characteristic of a section throughout said wide band of frequencies differs from a fixed phase shift at all of said frequencies by an amount proportional to the frequency.

4. The combination of claim 1, characterized by the fact that the intercept of said straight line on the phase axis at zero frequency is numerically greater than a predetermined value.

5. The combination of claim 1 characterized by the fact that the phase frequency characteristic of the equalizers are substantially straight lines over the effective signal band.

6. In a signal transmission system comprising a transmission line adapted for a plurality of channels, a plurality of repeaters in tandem in said line, means for increasing the ratio of signal to modulation products for the system comprising phase equalizing means introduced in the line at a plurality of intermediate points dividing the line into a plurality of electrically equal sections, the phase frequency characteristic of each equalizer plus its section within the utilized signal frequency band being linear except for departures from the linear represented by sinuosity of such character that a straight line drawn through any three points of the phase frequency characteristic within the signaling band will have a positive intercept greater than zero.

7. In a signal transmission system comprising a transmission line with a plurality of repeaters in tandem, each giving rise to a modulation voltage which 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 such that the phase frequency characteristic of the section within the range of utilized frequencies is substantially of the form $\varphi=\varphi_0+kf$ where φ_0 has a value numerically equal to or less than θ and the latter is defined by

$$\sin\frac{\theta}{2}\overline{\gtrless}\frac{E}{E_1}$$

8. In a signal transmission system comprising a transmission line adapted for a wide band of frequencies, a plurality of repeaters in tandem in said line giving rise to modulation, means to keep the cumulative modulation on said line below a predetermined maximum value comprising phase equalizing means introduced in the line at intervals dividing the line into electrically equal sections, said equalizers having such phase frequency characteristics that the portion of the characteristic of each equalizer plus its line section within the utilized frequency band approximates a straight line which when extrapolated to zero frequency has a phase intercept, at zero frequency, different from zero by a predetermined amount.

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