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H. K. KRIST

2,240,140

DISTORTION REDUCTION IN WAVE TRANSMISSION

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FIG. 1

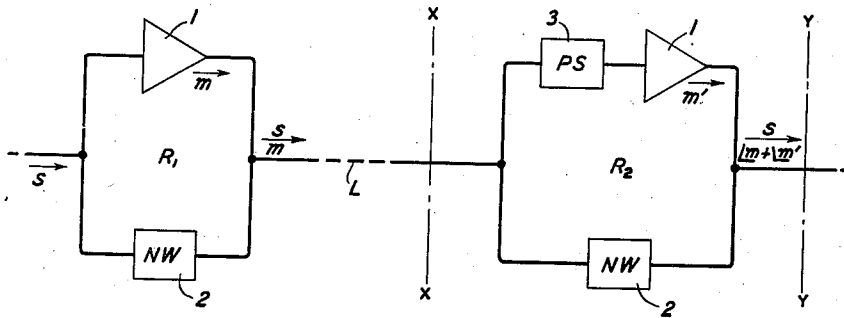


FIG. 3

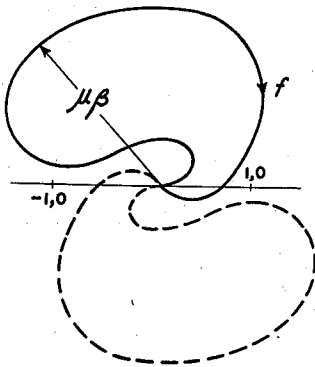


FIG. 2

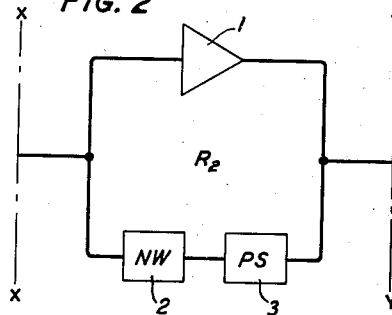


FIG. 4

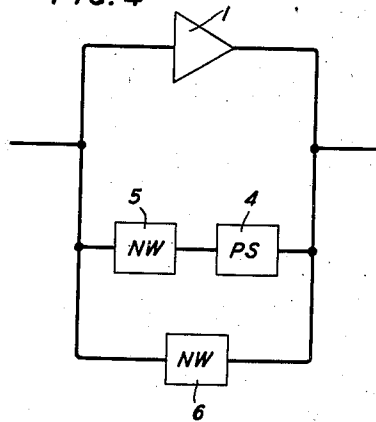
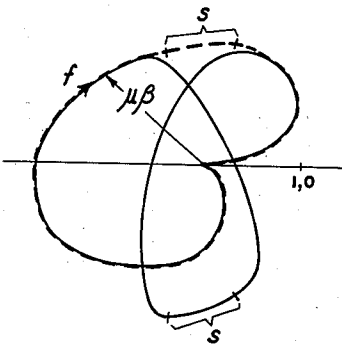


FIG. 5



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DISTORTION REDUCTION IN WAVE TRANSMISSION

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6 Claims. (Cl. 178-44)

This invention relates to electric wave transmission systems and more particularly to the control of amplitude distortion in signaling systems comprising a plurality of signal amplifiers in tandem relation.

Although electric wave amplifiers are designed and intended to yield a faithful amplified replica of the waves applied to them, even the best of them give rise in some degree to amplitude distortion. Such distortion appears in the form of modulation products, that is, harmonics of the various frequencies included in the applied waves and other products resulting from the interaction or intermodulation of those various frequencies. Where only a single amplifier is involved, the distortion products may be of such small amplitude as to be negligible. Where, however, the same waves are applied to a succession of amplifiers, as they would be in a long distance wire line transmission system having repeaters at intervals along the line, the modulation products generated in the several repeater amplifiers are all transmitted to the receiving end of the line and their cumulative effect may be quite substantial. How substantial the cumulative effect is depends in large measure on the phase relation between the distortion contributions from the several repeaters. If those contributions combine in aiding phase relation their effective or vector sum is directly proportional to the number of repeaters in the line, whereas if they are, for example, in random phase relation their vector sum is proportional to only the square root of the number of repeaters.

A general object of the invention is to control the phase relation of the modulation products in a system of the kind described and more particularly to obtain such relative phases that the modulation products are cumulative at less than linear rate. From another point of view, an object of the invention is to so adjust the relative phases of additive modulation products in the system that the modulation products generated at one point of the system are neutralized by those generated at other points. A more particular object is to secure desired phase relations between modulation products without incidentally and simultaneously causing phase delay distortion.

In accordance with the present invention, use is made of certain characteristics of the stabilized feedback amplifier to obtain the desired control over the relative phase of modulation products originating in the amplifier. One characteristic of such an amplifier is that the phase shift under-

gone by a wave in its transmission from the input terminals of the amplifier to the output terminals thereof is largely determined by the phase shift characteristic of the feedback or beta circuit of the amplifier, and the greater the degree of feedback the more nearly is the over-all phase shift of the amplifier determined solely by the beta circuit phase shift. On the other hand, if waves are generated or introduced at some point within the mu-beta loop of the amplifier rather than at its input terminals, the relative phase in which such waves appear at the output terminals is determined not by the beta circuit phase characteristic alone but by the phase characteristic of the entire mu-beta loop. The waves so generated or introduced may be distortion products arising from modulation in the mu circuit of the amplifier, hence it follows that the relative phase of such products can be adjusted over a wide range by adjusting the phase shift characteristics of the mu-beta circuit. More particularly, it is possible to adjust the relative phase of such products so that they do not combine arithmetically, that is, in phase with like modulation products generated at other tandem connected amplifiers. Advantageously, these modulation products are so controlled in relative phase that they neutralize or tend to neutralize each other.

The nature of the present invention will appear more fully in the following description of typical embodiments illustrated in the accompanying drawing. In the drawing:

Fig. 1 shows two repeaters in tandem with mu-beta circuit control of the modulation products; Figs. 2 and 4 show modified arrangements; and Figs. 3 and 5 show illustrative mu-beta characteristics.

Referring now to Fig. 1, there is illustrated schematically a system comprising a wire line with a multiplicity of like repeaters R_1, R_2 , etc., spaced apart therein for the transmission of signals S from a source to the left, not shown. The wire line may be a pair of coaxial conductors, for specific example, and the signals may be television signals, multiplex carrier telephone signals or of any desired alternating current type. Where there are many repeaters in the line, it has been found, as explained hereinbefore, that the modulation products generated in the various repeaters may combine in such phase relation that their sum total at the receiving end of the line tends to be excessive. The products that are especially troublesome in this regard are the third order modulation products of the form $2a-b$ where a and b are different frequency components of the

signal. These products and many others are generated in the repeater amplifiers and they are due principally to unavoidable slight non-linearity in the characteristics of the vacuum tubes comprising the amplifiers. At the output terminals of the first repeater R_1 , therefore, there appear in addition to the amplified signal S the various modulation products denoted by m , which are incidentally generated in the repeater amplifier. The repeater amplifiers are of the stabilized negative feedback type and they are conventionally represented as having a mu circuit comprising amplifying element 1 and a beta circuit comprising a network 2, and it will be assumed that the vectorial product mu-beta is large compared with unity throughout the frequency range occupied by the signals.

After transmission over the intervening line section L, both the signals and the modulation products m are applied together to the input terminals of a second repeater R_2 . Both pass through the amplifier and are restored in amplitude to the level obtaining at the output of repeater R_1 , for example. The phase shift undergone in passing through the amplifier is, in accordance with the characteristic of the type of amplifier described, determined substantially by the phase shift frequency characteristic of the beta circuit network 2. In repeater R_2 the signal S encounters the same kind of non-linearity as was encountered in the preceding amplifier. Hence, again there is generated a set of modulation products m' which are substantially the same as the modulation products m . The new modulation products, except for application of the present invention, would bear the same phase and amplitude relation to the signal S as obtains between products m and signal S , and, inasmuch as the latter relation is presumed to be not affected by the line L, it follows that the two sets m and m' of modulation products would tend to be in phase with each other at the output of repeater R_2 so that their vector sum would be twice the amplitude of either alone. Although the two repeaters are in all other respects alike, repeater amplifier R_2 is provided, in accordance with the invention, with a phase shifter 3 disposed in the mu-beta loop. As previously explained, any phase shift introduced in the mu-beta loop of the amplifier affects the phase relation between the modulation products generated therein and the signals giving rise to them, hence the modulation products m and m' are separated in phase by the amount of phase shift so introduced. If that phase shift is 180 degrees over the frequency range of interest, the two sets of modulation products are thereby adjusted to phase opposition whereby they tend to neutralize each other. In practice, of course, it is probable that the various sets of modulation products would not be exactly alike in amplitude and that perfect neutralization of the modulation products would not be quite achieved. For analytical purposes, however, each set of modulation products may be considered as comprising two components, one component being equal to the average value of all of the various sets of modulation products arising in the system and the other being the deviation from that average value, as explained in J. G. Kreer Patent No. 2,140,915, issued December 20, 1938. Components of the first kind are susceptible of complete neutralization in accordance with the invention. Components of the second kind, being random in distribution, tend to be additive on a power or root mean square basis.

If the relative mu-beta circuit phase shift in alternate repeaters is some value other than 180 degrees or a multiple thereof, the various sets of modulation products will combine vectorially with an angle between them so that the vector sum, although not reduced to zero, is at least less than twice the amplitude of either alone.

To obtain a mu-beta circuit phase shift of 180 degrees in repeater R_2 , it is necessary only to reverse any pair of leads in either the mu circuit or the beta circuit relative to their manner of connection in the repeater R_1 . Due care must be exercised, of course, in the design of repeater R_1 to insure that on introducing a phase shift of 180 degrees stable circuit conditions are maintained. The general criterion, in terms of Nyquist's rule with reference to the mu-beta frequency polar diagram, is that the mu-beta characteristic shall not enclose the point 1,0 for the amplifier circuit in either its "normal" condition or in its "poled" condition (wherein the phase shifter has been added). This can be accomplished in various ways. For example, a restricted criterion might be stated as follows: Design the "normal" amplifier so that its mu-beta characteristic does not enclose either the point 1,0 or the point -1,0. The mu-beta path can then be poled, i. e., reversed, at any convenient point in the circuit without producing instability. The poling in this case does not affect the magnitude of mu-beta at any frequency but only the phase relationship. Fig. 3 illustrates a possible mu-beta characteristic that conforms with the restricted criterion stated. The solid line curve represents the mu-beta plot of the normal amplifier and the dotted line curve represents that of the poled amplifier. It is evident that the introduction of a phase shift of 180 degrees rotates the polar diagram 180 degrees and that in both positions encirclement of the critical point 1,0 is avoided.

The phase shifter 3, which is understood as possibly constituting only a pair of reversed leads, is illustrated in Fig. 1 as being in the mu portion of the mu-beta loop where its presence has no substantial effect on the over-all phase frequency characteristic of the amplifier. It could, as indicated in Fig. 2, alternatively be included in the beta circuit where, although it would affect the over-all phase characteristic of the amplifier, the reversal of leads might be more readily effected, e. g., if the beta circuit were balanced with respect to ground, or if cathode feedback is employed. It should be understood that whereas the phase shifter 3 is represented as being a discrete element of the amplifier it can be incorporated, especially where a phase shift of other than 180 degrees is contemplated, with other circuit elements, for example, the elements comprising the interstage circuits of the mu circuit or those making up the beta circuit.

It should be understood that it is not essential to the principal objects of the invention that the phase reversal or other phase shift introduced into the mu-beta circuit as described extend over the entire frequency spectrum. It is sufficient, and preferable from a design standpoint, if the phase shift extends over only the frequency range occupied by the signals. Thus, the signal amplifier may comprise two feedback paths, one adapted to transmit only frequencies in the signal range and the other adapted only for frequencies outside that range, and the desired phase shift may be introduced in the first feedback path. Such an arrangement is illustrated

diagrammatically in Fig. 4 where the one feedback path comprises, in addition to phase shifter 4, a beta circuit network 5 that passes substantially only the signal frequencies and that has the phase shifting and attenuation characteristics desired in the signal range of the normal amplifier. The second feedback path comprises a network 6 that suppresses transmission through it in the signal frequency range and that has the phase shifting and attenuation characteristics desired outside the signal range of the normal amplifier. The mu-beta polar diagram of a typical amplifier of the kind contemplated in this paragraph is represented in Fig. 5 where the dotted line applies to the normal amplifier and the solid line applies to the poled modification of the normal. The frequency range occupied by the signals is designated s . Within this range, at least, the magnitude of mu-beta should be the same with and without inserted phase shift.

Where the phase shift is 180 degrees, as described, it may be introduced in alternate repeaters along the line as suggested in Fig. 1, but this condition is not essential and it is sufficient if merely half of the repeaters introduce 180 degrees phase shift and half do not. The preferred arrangement depends upon the characteristics of the particular system. If before the use of poling, some modulation product, such as $2a-b$, is directly additive with respect to the individual repeater sources, then poling of the mu-beta paths of one-half the repeaters will reduce this direct addition as explained previously. If this poling is done at random along the line, then this improvement is obtained without producing any degradation of other order modulation products regardless of what their phase increments were before poling. If the poling is done according to a fixed pattern, i. e., if particular repeater points along the line are poled, the repeater points at which poling is done should be chosen in accordance with the characteristics of the particular system, in order that no other modulation product may be caused to accumulate to a greater value, in its addition along the line, than it had previously to the poling. Thus, if repeaters Nos. 1, 3, 5, etc., are poled and if the particular system before poling had a phase increment of 180 degrees for some modulation product m_n , then after poling m_n would become cumulative; but if the poling in this system is done at repeater points Nos. 3, 4, 7, 8, 11, 12, etc., then the product m_n is not degraded by the poling while the " $2a-b$ " modulation product is improved as previously explained.

The advantage of the invention may be realized also where the shift introduced is less than 180 degrees. Thus, for specific example, three different amplifiers could be used in equal number along the line, the amplifiers differing only in that their mu-beta phase shifts differ from each other by 120 degrees over the desired transmission frequency band. The vector sum of the modulation products would then tend to approach zero. Again, the phase shift between the three amplifiers might be, for example, 100 degrees, that is, zero in one of the three amplifiers, +100 degrees in the second, and -100 in the third, and the net modulation substantially eliminated by adjusting the amplitudes of the several modulation vectors, as by control of the absolute magnitude of the vectorial product mu-beta, to such relative values that the vector sum is zero.

Although the present invention has been described with reference to specific embodiments thereof, it will be appreciated that it is susceptible of a variety of other embodiments within the spirit and scope of the appended claims.

What is claimed is:

1. In a signaling system, a long transmission line having a plurality of signal amplifiers of the stabilized feedback type spaced apart therein, each of said amplifiers tending to generate third order modulation products resulting from amplitude distortion of the signals transmitted through the said line and each of said amplifiers having a mu-beta circuit, said amplifiers comprising a plurality of each of two different kinds in substantially equal numbers, said two kinds differing substantially only in that the phase shift frequency characteristic of the mu-beta circuits of amplifiers of the one kind differs by approximately 180 degrees from the corresponding characteristic of amplifiers of the other kind, whereby said modulation products generated in amplifiers of the one kind are effectively reduced by like modulation products generated in amplifiers of the other kind.

2. In a signaling system, a long transmission line having a plurality of each of a plurality of n different kinds of signal amplifiers of the stabilized feedback type spaced apart therein, said different kinds of amplifiers differing substantially only in respect of the phase shift frequency characteristic of their mu-beta circuits, the phase shift difference between said different kinds of amplifiers being substantially

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

radians throughout the frequency range occupied by the signals transmitted.

3. In an electrical signaling system, the method of neutralizing modulation products generated by amplitude distortion of an electrical signal which comprises applying said signal and modulation products to a stabilized feedback amplifier tending to generate like distortion products and adjusting the phase-frequency characteristic of the mu-beta circuit of said amplifier to bring the said products generated therein into neutralizing relation with the said applied products.

4. A source of signals and third order modulation products resulting from amplitude distortion of said signals, a stabilized feedback amplifier connected to said source to receive said signals and products, said amplifier generating like modulation products by amplitude distortion of said said signals, the mu-beta phase shift of said amplifier being of such magnitude that said products generated therein tend to neutralize the products from said source.

5. In a signaling system, a long transmission line having a multiplicity of each of at least two different kinds of repeater amplifiers spaced at intervals therein, each of said repeater amplifiers being of the stabilized feedback type having a mu-beta circuit and each causing incidental amplitude distortion of the signals transmitted, the said different kinds of amplifiers substantially differing from each other in respect of the phase shift characteristics of their mu-beta circuits, whereby the distortion contributions of the several amplifiers are cumulative in out of phase relation.

6. In a signaling system, a transmission line having signal amplifiers of the stabilized feedback type spaced apart therein, each of said

amplifiers having a mu-beta circuit and incidentally generating third order modulation products by distortion of the signals applied, said amplifiers comprising a plurality of each of a plurality of different kinds, the mu-beta circuits of the said different kinds of amplifiers having mutually different phase shift-frequency characteristics so

correlated with the relative amplitudes of the modulation products respectively generated by them that the vector sum of the modulation products from one of each of said different kinds of amplifiers is substantially zero.

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