Feb. 25, 1941. E. PETERSON 2,233,061

CONTROL OF DISTORTION

Filed Feb. 18, 1939

FIG. 1

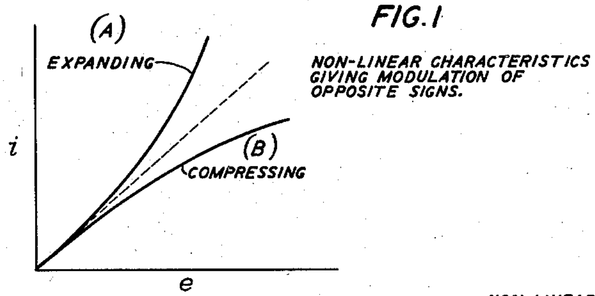


FIG. 2

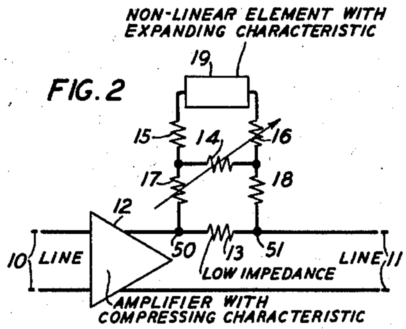


FIG. 3

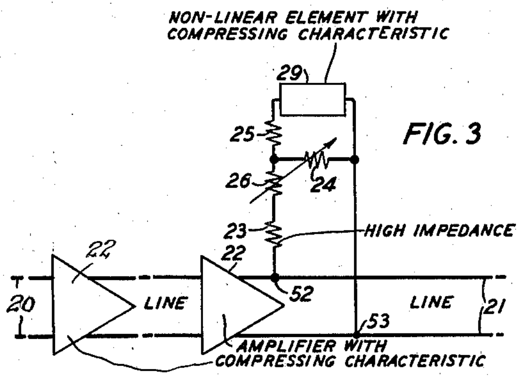


FIG. 4

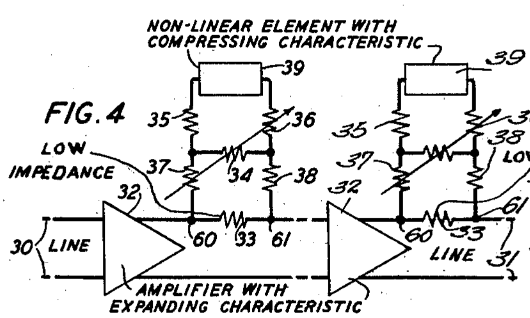


FIG. 5

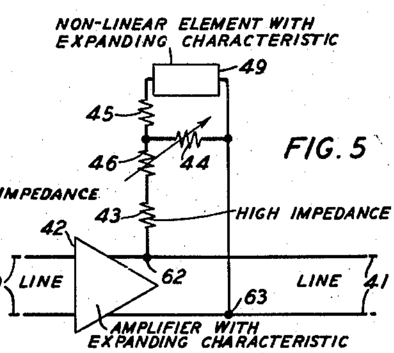
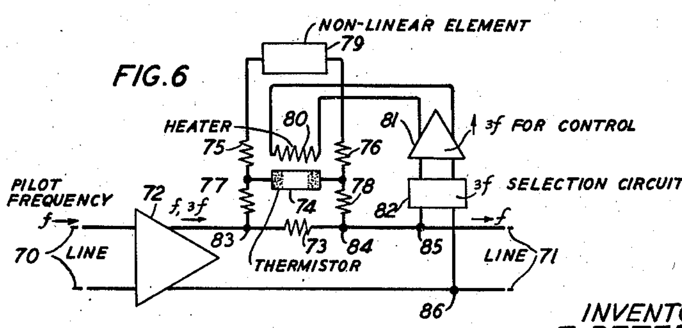


FIG. 6



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2,233,061

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2,233,061

CONTROL OF DISTORTION

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14 Claims. (Cl. 178—44)

This invention relates to means for the correction of distortion in electrical transmission systems and particularly to the correction of distortion arising in vacuum tube amplifiers. More particularly it relates to correction of non-linear distortion in signal transmission systems in which there is little phase distortion and in which a large number of vacuum tube amplifiers or repeaters are employed.

It is well known that vacuum tube amplifiers as used in communication produce in their outputs certain modulation products of the signals amplified. The amplitude of these modulation products from a single repeater is ordinarily small in comparison with the amplitude of the signals from which they are formed and they therefore become significant only in systems employing a large number of repeaters in series. In the past the modulation products even in systems in which a comparatively large number of repeaters contributed have not caused serious concern since satisfactory control has been obtainable by such means, for example, as that disclosed in my Patent 1,927,070, issued September 19, 1933, and in other art referred to therein. Also, since due to phase shift in line and repeater units the modulation products have tended to assume a random phase, power rather than amplitude addition has resulted.

In the proposed coaxial cable system in which phase shift is small the modulation product tends to add up in phase to give a total amount of amplitude proportional to the number of repeaters. Thus in a four thousand mile system with eight hundred repeaters, such as the proposed 2-megacycle coaxial system, amplitude addition of modulation products gives a total amount of modulation from the system, 58 decibels greater than from one repeater whereas power addition would give only 29 decibels more.

The products which give most difficulty are the third order types $2p-q$ and $p+q-r$. These products are unaffected by poling and in general will add in phase from repeater to repeater except for phase shift due to curvature of the phase-frequency characteristic. Since in broad band systems the amount of phase curvature tends to be small especially for products involving channels located near each other in frequency, virtual amplitude addition from all sources of certain third order products occurs.

It is the object of this invention to control signal distortion by modulation, particularly modulation giving rise to certain third order products, especially those third order products for the control of which the methods now in use are not effective.

These third order modulation products may, in general, be of two sorts, distinguished by a positive or negative sign, and produced by a device of the "expanding" or of the "compressing" type. Thus the voltage versus current characteristic of a third order generator of the expanding type may be expressed by the equation $i=a_1e+a_3e^3$ and of the compressing type by the equation $i=a_1e-a_3e^3$. It is apparent that if currents as represented by these two equations were superposed upon each other in the same circuit, the third order terms would tend to cancel each other out.

Now it has been found that the broad band feedback amplifiers proposed for use on the 2-megacycle coaxial system referred to have compressing characteristics of the general type defined by the expression $i=a_1e-a_3e^3$. Hence, if non-linear elements having characteristics of the expanding type as defined by the general expression $i=a_1e+a_3e^3$ are inserted at suitable places in the system, third order modulation is thereby produced which is of opposite sign to that of the amplifier and a reduction of the total modulation may be obtained. A mixture of silicon carbide and a binder material as described in McEachron Patent 1,822,742, September 8, 1931, forms a non-linear element which may have such characteristics. Another example may be found in a copper oxide rectifier assembly.

For a more complete understanding of the invention reference is made to the drawing in which:

Fig. 1 shows characteristic current versus voltage curves for non-linear devices having respectively expanding and compressing characteristics;

Fig. 2 illustrates in schematic diagram a method for the use of a non-linear element having an expanding characteristic to control the third order modulation production from repeaters having a compressing characteristic;

Fig. 3 is a similar diagram in which the non-linear element is of the compressing type and the repeater is of the compressing type;

Fig. 4 is a similar diagram in which the non-linear element is of the compressing type and the repeater is of the expanding type;

Fig. 5 is a similar diagram in which the non-linear element is of the expanding type and the repeater is of the expanding type; and

Fig. 6 is a schematic diagram illustrating a means for employing a pilot wave to control the output of third order modulation products from a non-linear element.

Plotted against current as ordinates and voltage as abscissae representative curves of third order modulation product generators are shown in Fig. 1. Curve A is a plot of the equation $i=a_1e+a_3e^3$ which may be the characteristic of the so-called expanding device. Curve B is a plot of the equation $i=a_1e-a_3e^3$ which may be the characteristic of the so-called compressing device.

In Fig. 2 is shown a section of a line having input at 10, output at 11 and equipped with repeater 12. It is to be assumed that the line is continued through a plurality of additional sections to the left from 10 and to the right from 11. On one side of the output portion of the line section an impedance 13 is connected between taps 50, 51. Impedance 13 may be a resistor of such value as to cause insubstantial line unbalance. The repeater 12 may be a vacuum tube amplifier having a compressing characteristic as to its generation of third order modulation products and the non-linear element 19 connected across impedance 13 through the variable attenuator consisting of variable impedances 14, 15, 16, 17 and 18 may be assumed to have an expanding characteristic. Since the element 19 is a much more efficient harmonic generator than is repeater 12 the attenuator may be used in spite of the low value of impedance 13.

If it be assumed that the composite wave entering repeater 12 through the line at 10 comprises waves of frequencies p and q the output of repeater 12 into the line may be assumed to contain, among other components, the frequencies p, q and a small amount of frequency $2p—q$. There will be a drop of potential across impedance 13 at these frequencies causing a flow from tap 50 through impedances 17, 15, non-linear element 19 and impedances 16, 18 to tap 51 and thence on down the line. The current entering element 19 may be assumed to be composed of frequencies p and q with a small amount of frequency $2p—q$ and the output current from element 19 may then be assumed to be composed of p, q, $2p—q$ and a quite insignificant amount of other terms derived from the small amount of $2p—q$ that entered element 19. The impedances 13 to 18, inclusive, are made substantially pure resistances, and the third order production characteristics of non-linear element 19 is substantially the converse of the third order production characteristic of repeater 12 so that the characteristic of the one may be represented by a curve similar to curve A of Fig. 1 and of the other by a curve similar to curve B of Fig. 1. Accordingly the $2p—q$ frequency component generated in element 19 and entering the line at 51 will be substantially 180 degrees out of phase with the $2p—q$ frequency component generated in repeater 12 and flowing through impedance 13 to point 51 and hence these separately generated $2p—q$ components will tend to neutralize each other in the line. If the output from element 19 is properly proportioned as by adjustment of attenuators 14, 15, 16, 17, 18 there may be approximate cancelation of the $2p—q$ component.

It is to be noted at this point that, although for purposes of a simple illustration, the discussion has been confined to but one of the third order modulation products as $2p—q$, under the assumptions made these results of neutralization apply also to the other third order products so that Fig. 2 illustrates in diagrammatic form a means for the control of all third order modulation products.

In Fig. 3 a line section having input reference point 20 and output reference point 21 is equipped with repeaters 22 comprising amplifiers having a compressing characteristic. A non-linear element 29, also having compressing characteristics, is bridged across the output line at 52, 53 through a high impedance 23 and a variable attenuator 24, 25, 26. The impedance 23 may have so high a value in view of the high efficiency of element 29 as a third order generator that the bridge is an insubstantial shunt upon the line.

The compensating or neutralizing action of the non-linear element 29 of Fig. 3 upon the output of repeater 22 is substantially equivalent to the action of element 19 upon the output of repeater 12 of Fig. 2. To accomplish this, since both amplifiers and non-linear elements are of similar, that is, compressing type, the neutralizing circuit is connected across the line instead of essentially in series with it as in Fig. 2. Thus the current entering the impedance 23 is in phase with the current flowing in the line at tap 52 and since impedances 23, 24, 25, 26 are assumed to produce no phase shift, the output third order modulation product from non-linear element 29 will be in phase with third order modulation products produced by repeaters 22 and flowing in the line at tap 52. However, the current in the other side of the line as at tap 53 will be 180 degrees out of phase with the current at 52 and hence the third order component entering the line at 53 from element 29 will be 180 degrees out of phase with the third order component current flowing in the line at that point and, accordingly, neutralization of third order components will occur as in the arrangement of Fig. 2.

The line section of Fig. 4 having input reference terminal 30 and output reference terminal 31 is equipped with repeaters 32 which are assumed to have an expanding characteristic. A low impedance 33 in one side of the output line of each repeater is bridged at 60, 61 by a neutralizing circuit comprising a non-linear element 39 having a compressing characteristic and interposed therebetween a variable attenuator 34, 35, 36, 37, 38. It will be apparent that the arrangement of Fig. 4 is identical with that of Fig. 2. In Fig. 4 the repeater is of the expanding type and the compensating non-linear element is of the compressing type whereas in Fig. 2 the repeater is compressing and the non-linear element expanding. Thus, since the repeater and the non-linear element are of opposite type in both Fig. 2 and Fig. 4 and since the two circuit arrangements are identical, the process of neutralization of third order products may be presumed to be the same for the arrangement of Fig. 4 as that already described in relation to Fig. 2.

The arrangement of Fig. 5 is likewise identical with that of Fig. 3 having a line section defined at input 40 and at output 41 and equipped with a repeater 42 assumed to have an expanding characteristic. Bridged across the output section at 62, 63 is a neutralizing circuit comprising high impedance 43, variable attenuator 44, 45, 46 and expanding non-linear element 49. In the arrangement of Fig. 5 as in that of Fig. 3 the repeater and the non-linear element have third order production characteristics of the same type and the process of neutralization of third order products is the same in each.

Thus the invention discloses means for the control of the third order modulation products of a repeater or other circuit device which comprises connecting in series in the output circuit of the said device a source of third order products having a third order production characteristic which is the converse of the third order production characteristic of said circuit device, or, alternately, bridging across the output circuit of said device a source of third order products having a third order production characteristic which is of the same type as the third order production characteristic of the said circuit device.

In the specific arrangement of Figs. 3 to 5, inclusive, there is shown a line section equipped with a single repeater and associated therewith a means for the control of third order modulation products. It will be apparent that whereas precise control may at times be more readily achieved by associating a control unit with each source of third order modulation or, more specifically, by associating a properly regulated non-linear element with each repeater, such an arrangement is not a requisite to the practice of the invention and the attainment of beneficial results therefrom. In many cases satisfactory results may be obtained by spacing the control means at considerable intervals along the line and adjusting the neutralizing modulation products therefrom to compensate for the modulation products resulting from a plurality of repeaters. Thus the compensating means may be applied at or subsequent to each repeater or alternately spaced at intervals of two or more repeaters.

Moreover when the phase distortion arising in a unit line section is small as will often be the case, and when the number of such sections in which compensating means is provided, is comparatively large, it may not be necessary or particularly valuable to balance precisely the modulation generated in a line section by means of nice control of the output of a distorter associated therewith. A statistical balance may be quite good enough. In this case the average outputs of repeaters and distorters are made equal in magnitude and are combined so as to be opposite in sign. Thus individual distorter adjustments may be dispensed with.

Although it is not expected that the attenuator controlling the output of modulation products from the compensating elements will ordinarily require frequent adjustments there is obvious advantage in arranging that such adjustment when and if required shall not require manual manipulation. Particularly, where precise adjustment is of importance, or where a single compensating element is designed to neutralize the modulation products of a plurality of repeaters, means for automatic adjustment becomes important. A preferred form of such an automatic means is shown in the diagram of Fig. 6. The particular form illustrated is that applicable to the case in which the repeaters and the non-linear elements are of unlike characteristic although it is obvious that the principle involved is readily applicable to the case in which the repeaters and non-linear elements have like characteristics, in which case the output from the non-linear element would be connected to bridge the output line as in Figs. 3 and 5.

A line section defined at **70** and **71** is equipped with a repeater **72**. In the repeater output line is a low impedance **73** bridged at **83, 84** by a circuit comprising non-linear element **79** and a variable attenuator having series impedances **75, 76, 77, 78** and shunt impedance **74** which may be a unit having a high temperature coefficient of resistance. Such units are sometimes given the name "thermistor." In close proximity with impedance **74** is heater **80** such that the resistivity of impedance **74** is a direct function of the current flowing in heater **80**. Bridged across the output line at **85, 86** is selective circuit **82** feeding an amplifier **81** in the output circuit of which is heater **80**.

The operation of the automatic modulation control in the specific embodiment of Fig. 6 may be described as follows: Let f represent the frequency of a single frequency pilot wave transmitted over the line and amplified by repeater **72**. Since repeater **72** is assumed to be subject to the production of third order modulation, there will appear in the output of repeater **72** a component of frequency $3f$. If this component is not neutralized by the output from non-linear element **79** it will cause a difference of potential across the bridge at **85, 86** and thus current at frequency $3f$ will pass through selective circuit **82** which is proportioned to pass only frequency $3f$ to amplifier **81** and thence to heater **80**. This output current of amplifier **81** passing through heater **80** will raise the temperature of shunt element **74** thus increasing its impedance and causing a greater output of modulation products from non-linear element **79**, thus tending to neutralize the modulation products in the line coming from repeater **72**. Thus the automatic control is adapted to hold the contents of modulation products in the line to a tolerable value. There is presumed such a proportioning of the several elements of the control that the modulation products arising in the line devices will in general somewhat exceed in amplitude the out-of-phase products contributed by the control circuit.

Thus a broad band transmission system equipped with a plurality of repeaters might employ modulation control of the type shown in Figs. 2 to 5, inclusive, arranged to be permanently or semipermanently adjusted as to output and spaced as desired. At relatively larger intervals pilot wave controlled automatic modulation neutralizers of the type illustrated by the diagram of Fig. 6 might be employed and thus adapted to compensate for the insufficiency of the fixed modulation compensators.

Although the invention has thus been illustrated and described as applying to particular arrangements, it will be apparent that many other embodiments may be employed without departing from the spirit of the invention as defined by the claims.

What is claimed is:

1. A transmission system comprising in combination a transmission line adapted to transmit signal waves within a frequency band, on said line a plurality of repeaters subject to the production of modulation products, means to provide a pilot wave on said line within said frequency band, and modulation producing means controlled by said pilot wave operating to suppress said modulation products.

2. In a communication system a transmission line transmitting a band of frequencies, distributed along said line a plurality of repeaters subject to the production of modulation products, interspaced between said repeaters on said line a plurality of means adapted to produce modulation products of the same order as those produced by said repeaters, the connection of said means to said line such that the modulation products of said means tend to suppress the modulation products of said repeaters on said line,

and pilot wave control of the modulation output of said means.

3. A transmission system comprising in combination a transmission line adapted to transmit signal waves within a frequency band, on said line a plurality of repeaters subject to the production of third order modulation products, interspaced between said repeaters a plurality of non-linear elements adapted to the production of third order modulation products, means for connecting said non-linear elements to said line whereby third order modulation products of said non-linear elements appear in phase opposition to third order modulation products of said repeaters, means transmitting a pilot wave on said line within said frequency band, and pilot wave operated means controlling the output of said non-linear elements.

4. A signal wave transmission system comprising in combination a transmission line adapted to transmit signal waves within a frequency band, on said line a plurality of repeaters subject to the production of third order modulation products, interspaced between said repeaters a plurality of non-linear elements adapted to the production of third order modulation products, means for connecting said non-linear elements to said line whereby third order modulation products of said non-linear elements appear in phase opposition to third order modulation products of said repeaters, variable attenuators adapted to control the output of said non-linear elements, means providing a pilot wave on said line and pilot operated means for controlling the adjustment of said attenuators.

5. A signal wave transmission system comprising in combination a transmission line transmitting signal waves within a frequency band, said line equipped with a plurality of repeaters subject to the production of modulation products, interspaced between said repeaters a plurality of non-linear elements adapted to the production of similar modulation products, means for so connecting said non-linear elements to said line that the modulation products of said non-linear elements are superposed on said line in phase opposition to similar modulation products of said repeaters, variable attenuators adapted to control the output of said non-linear elements, said attenuators comprising at least one element having a high temperature coefficient, a pilot wave channel on said line, and pilot wave means for controlling the temperature of said element of high temperature coefficient.

6. In a communication system a transmission line transmitting signal waves within a frequency band, distributed along said line a plurality of repeaters subject to the production of modulation products, interspaced between said repeaters and said line a plurality of non-linear elements adapted to produce similar modulation products, the connection of said non-linear elements to said line such that the modulation products of said non-linear elements are superposed in phase opposition to similar modulation products of said repeaters, means for control of the output of said non-linear elements comprising an attenuator having a variable element, and means for the control of said variable element by a modulation product on said line.

7. In a communication system a transmission line transmitting signal waves within a frequency band, distributed along said line a plurality of repeaters subject to the production of modulation products, interspaced between said repeaters and said line a plurality of non-linear elements adapted to generate similar modulation products, the connection of said non-linear elements to said line such that the modulation products of said non-linear elements are superposed upon said line in phase opposition to the modulation products of said repeaters, a pilot wave channel within said frequency band upon said line, means for the adjustment of the output of some of said non-linear elements to approximately neutralize the average amplitude of the modulation products on the line at their respective points of line connection, and means for the automatic adjustment of the output of others of said non-linear elements under the control of a modulation product of said pilot wave.

8. In a communication system comprising a line transmitting signal waves and equipped with a plurality of repeaters subject to the production of third order modulation products, the method of reducing the energy of said modulation products which consists in independently generating similar modulation products, superposing them upon said line in phase opposition to said repeater produced modulation products, and regulating the amplitude of said independently generated modulation products under the control of a third order modulation product of a pilot wave transmitted over said line.

9. In a communication system comprising a line transmitting signal waves and equipped with a plurality of transducers subject to the production of modulation products, the method of controlling the amplitude of said modulation products upon said line which consists in independently generating similar modulation products and superposing them upon said line in phase opposition to said transducer produced modulation products at a fixed amplitude substantially equivalent to the average amplitude of said transducer produced modulation product thereon, and independently generating other similar modulation products and superposing them upon said line in phase opposition to said transducer produced modulation products under the control of a modulation product of a pilot wave.

10. A signal wave transmission system comprising a transmission line, in said line a plurality of repeaters subject to production of modulation products tending to accumulate from repeater to repeater, means for transmitting a pilot wave on said line, a non-linear element associated with one of the repeaters of such character as to generate modulation products substantially equivalent to the accumulated modulation products, means whereby said equivalent modulation products may be interposed in phase opposition to the accumulated modulation products and means operated by said pilot wave for controlling the output of said non-linear element.

11. A signal wave transmission system comprising a transmission line, in said line a plurality of repeaters spaced at intervals along the line and subject to the production of modulation products tending to accumulate from repeater to repeater, means for transmitting a pilot wave on said line, a non-linear element associated with each individual repeater which in large part neutralizes the distortion due to each repeater, an additional non-linear element in the circuit which neutralizes the residual accumulated distortion due to a group of repeaters and means operated by said pilot wave for controlling the output of said additional non-linear element.

12. A signal wave transmission system com-

prising a transmission line, in said line a plurality of repeaters subject to production of modulation products tending to accumulate from repeater to repeater, a non-linear element associated with one of the repeaters of such character as to generate modulation products substantially equivalent to the accumulated modulation products, means whereby said equivalent modulation products may be interposed in phase opposition to the accumulated modulation products, and means operated in accordance with the magnitude of uncompensated modulation products present after such equivalent modulation products have been so interposed for controlling the magnitude of the interposed modulation products.

13. In combination, an electrical wave amplifier having the property of producing distortion in the output waves, means separate from said amplifier for generating counter-distortion and applying said counter-distortion to the circuit of said amplifier in such manner as to neutralize in part said distortion, and means operating in response to the magnitude of distortion remaining after such neutralization for controlling the output of said counter-distortion generating means.

14. In a repeater system for a transmission line, means for transmitting signals over said line, an amplifying repeater in said line, said repeater having the property of producing distortion in the output waves therefrom, means coupled to the line on the output side of said repeater for producing from the output waves of said repeater counter-distortion and adding such counter-distortion to the output waves from said repeater in such sense as to reduce the magnitude of the distortion appearing in the line, variable means to control the amount of the counter-distortion so added, and means operated in response to the magnitude of distortion remaining after such reduction of distortion for controlling said variable means.

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