Aug. 16, 1932. H. S. HAMILTON 1,871,986

METHOD AND MEANS FOR REDUCING DISTORTION OF VACUUM TUBE AMPLIFIERS

Filed Sept. 11, 1930

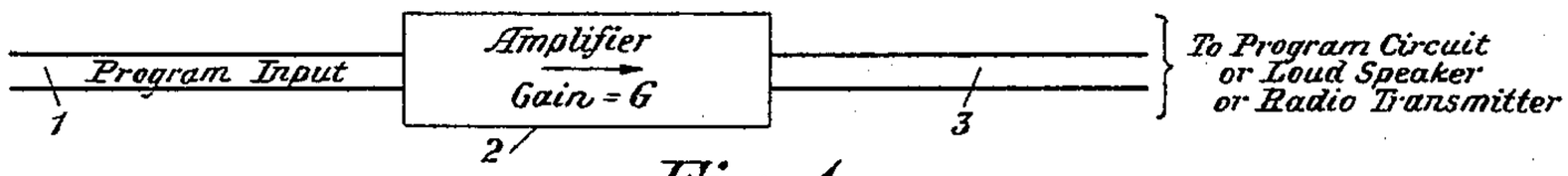


Fig. 1

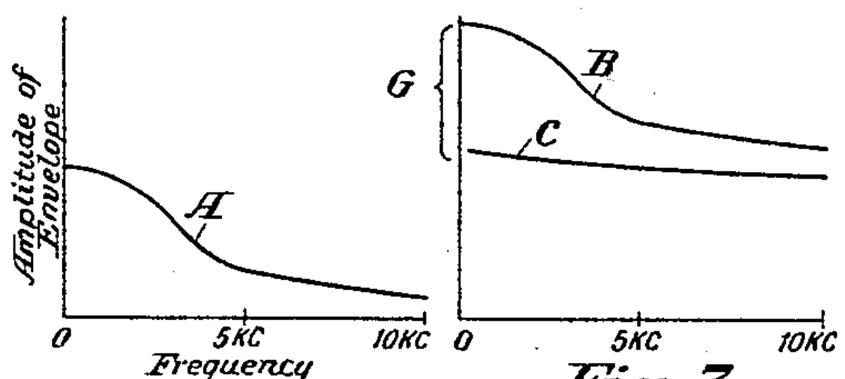


Fig. 2

Fig. 3

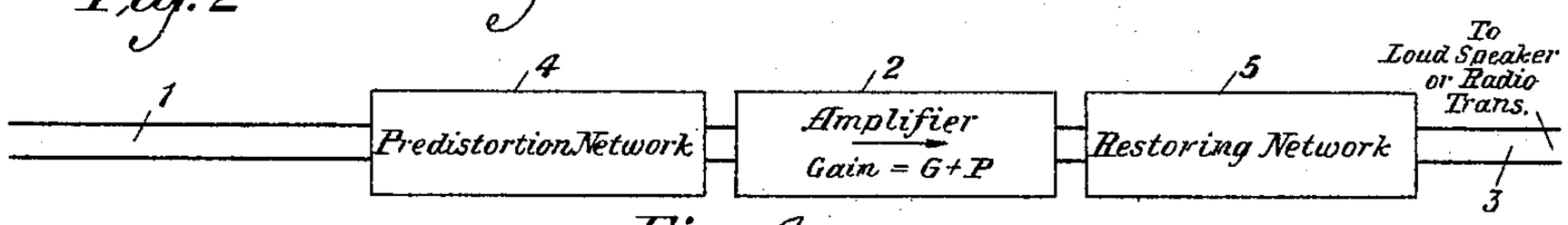


Fig. 4

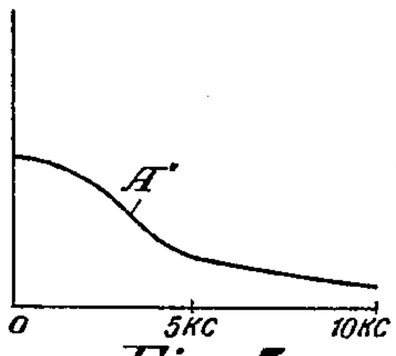


Fig. 5

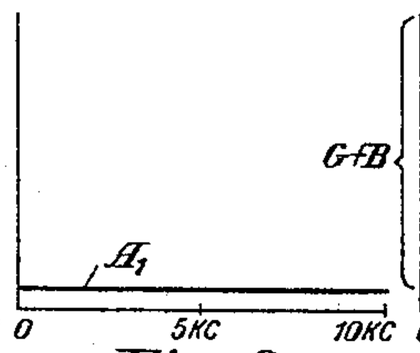


Fig. 6

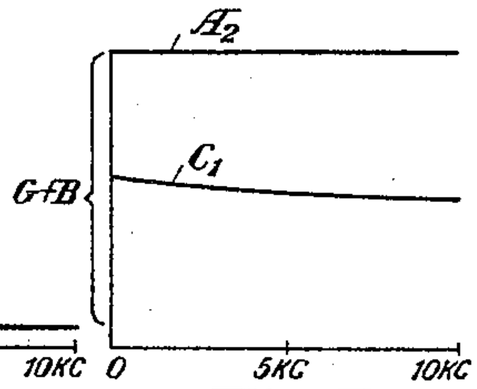


Fig. 7

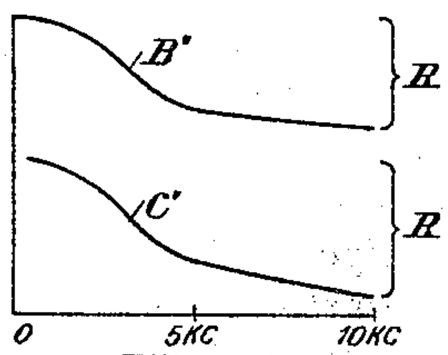
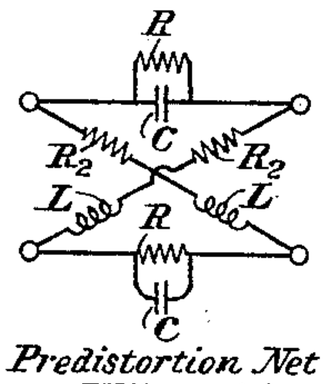


Fig. 8



Predistortion Net

Fig. 11

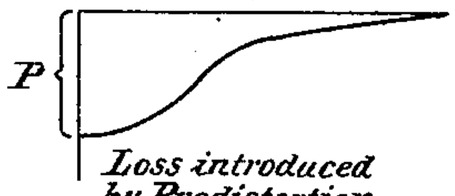
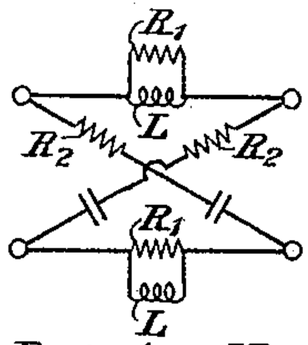


Fig. 9



Restoring Net

Fig. 12

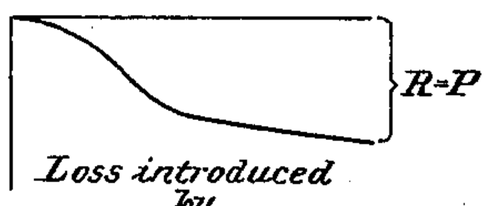


Fig. 10

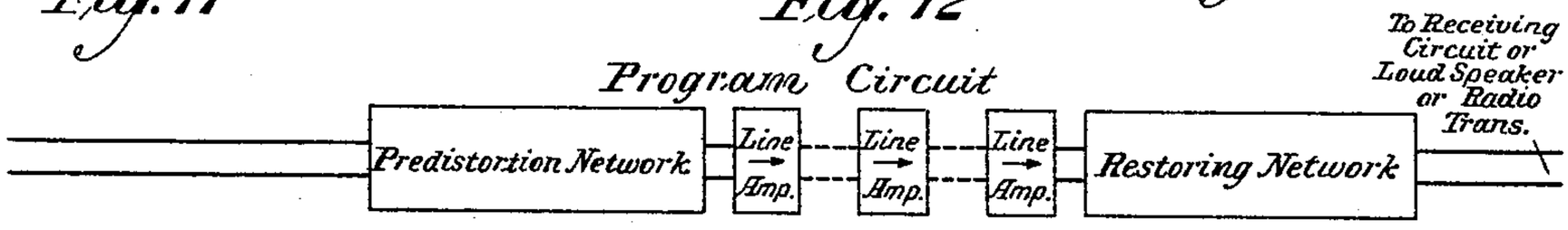


Fig. 13

INVENTOR
H. S. Hamilton
BY William R. Ballard
ATTORNEY

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UNITED STATES PATENT OFFICE

HAROLD S. HAMILTON, OF WHITE PLAINS, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK

METHOD AND MEANS FOR REDUCING DISTORTION OF VACUUM TUBE AMPLIFIERS

Application filed September 11, 1930. Serial No. 481,251.

This invention relates to a method and means for reducing the distortion effects caused by the overloading of the vacuum tubes of an amplifier.

Experience has shown that when a loud speaker, that transmits efficiently up to 3000 cycles, is operated from an amplifier whose last vacuum tube has a particular rated output, it is possible to operate such system with a certain maximum output from the vacuum tubes before the distortion effects produced by overloading become objectionable. If, then, a loud speaker that transmits efficiently frequencies up to 5000 cycles, be substituted for the loud speaker whose upper limit is 3000 cycles, and the amplifier is operated at the same maximum output as before, distortion effects previously not noticeable become objectionable. Those distortion effects are due to harmonics generated by the vacuum tubes of the amplifier, and in the frequency range above 3000 cycles the amplitude of those harmonics is large in comparison with the amplitude of that portion of the wave representing speech, music or other program material within the same range of frequencies. Since the first mentioned loud speaker cut off at 3000 cycles, such distortion is not noticeable, but with the employment of the loud speaker that operated up to 5000 cycles, the distortion of the speech currents in the upper range of frequencies was of such magnitude as to be objectionable. Heretofore it has been necessary to reduce the load on the last stage of the amplifier in order to reduce such distortion to the point where it would not be objectionable. In recent tests using a loud speaker that was efficient up to 10,000 cycles, it became necessary to reduce the output volume of the amplifier system several decibels below its rating when used with a loud speaker that was efficient up to about 4500 cycles. Such distortion may be avoided by substituting tubes of larger power capacity when loud speakers having greater frequency range are employed, but it is obvious that such expedient is neither economical nor desirable.

The present invention resides in a method and means for minimizing the distortion effects produced by the overloading of a vacuum tube amplifier without increasing the power-carrying capacity of the vacuum tubes.

This invention will be clearly understood from the following description when read in connection with the attached drawing, of which Figure 1 represents an amplifier system of the prior art; Figs. 2 and 3 are graphs illustrating the characteristics of the system shown in Fig. 1 that cause the distortion effects referred to above; Fig. 4 is a schematic representation of a system embodying the invention; Figs. 5 to 10, inclusive, are graphs illustrating the operation of the system shown in Fig. 4; Figs. 11 and 12 show predistortion and restoring networks, respectively, that may be employed in connection with Fig. 4; and Fig. 13 illustrates another system embodying the invention that differs from that of Fig. 4 in that it represents the use of a plurality of amplifiers associated with a circuit between the networks.

In Fig. 1, 1 represents an input circuit to an amplifier 2, which in turn is connected with an output circuit 3. The input circuit is an audio frequency circuit such as a pick-up circuit for transmitting a program from a studio to the point where the amplifier is located; or it may be the low frequency, low power circuit of a radio receiver, or the input circuit of an amplifier from a phonograph pick-up. The output of the amplifier may be impressed either upon a program circuit for transmission to more distant points or it may be connected with a loud speaker or a radio transmitter. Such an amplifier has a particular rated output carrying capacity represented by W and is operated at a gain represented by G.

The wave that is impressed by the circuit 1 upon the amplifier 2 contains many components of different frequencies. The amplitudes of those components are usually much greater in some parts of the range of transmitted frequencies than in others. The curve A of Fig. 2 shows a distribution of these amplitudes such as might be found in various types of program material, as for example, musical selections, speech, etc. The ordinates

of this curve represent the relative amplitudes of the components having the frequencies corresponding to the abscissæ. The amplitudes are shown in logarithmic units, such as decibels. The wave corresponding to A, after being amplified by the amplifier 2, would have the distribution represented by curve B of Fig. 3. There is also present in the output of that amplifier a wave representing the harmonics produced by the vacuum tubes of the amplifier. The curve C of Fig. 3 represents the distribution of the harmonics generated by the vacuum tubes. It will be clearly seen that at the lower frequencies the amplitude of the wave corresponding to curve C is a small fraction of the amplitude at the same frequencies of the wave corresponding to curve B. On the other hand, the amplitudes of the harmonics in the high frequency range closely approach the amplitudes of the components of the speech or other material in the same frequency range as shown by the close approach of curve C to curve B. The result is that in the higher frequency range the transmitted material, such as music or speech, is masked by the large amount of energy in the same frequency range that is produced by the overloading of the vacuum tubes of the amplifier.

Fig. 4 shows an arrangement by which the detrimental effects due to overloading of a vacuum tube amplifier may be greatly reduced. In Fig. 4 the program input circuit 1 is connected to a predistortion network 4 instead of being connected directly to the amplifier, as in Fig. 1. The predistortion network is in turn connected to the input of the amplifier 2 and the output of that amplifier is connected to a restoring network 5 which in turn is connected to the circuit 3. The predistortion network 4 which may have the form shown in Fig. 11 is designed to introduce large losses at low frequencies and relatively decreasing losses with higher frequencies. The transmission characteristic of the predistortion network is shown in Fig. 9 wherein the ordinates represent loss in logarithmic units, and the abscissæ represent frequency. The loss characteristic shown in Fig. 9 is the inverse of curve A of Fig. 2, that is, the relative amplitude, expressed in decibels from curve A of Fig. 2, minus the loss at the same frequency from Fig. 9 is a constant. The restoring network 5 has the characteristic represented in Fig. 2 which is the inverse of that shown in Fig. 9.

The manner in which the system of Fig. 4 functions to obtain the objects of the invention is as follows:

Let it be assumed that a wave whose components are distributed in accordance with curve A′ of Fig. 5 (which is similar to A of Fig. 2) is impressed upon the predistortion network 4. Since that network has the loss characteristic shown in Fig. 9, the amplitude-frequency distribution of the speech or music will be so modified that when the wave is impressed upon amplifier 2 it will have the distribution of components represented in Fig. 6. The wave impressed upon the amplifier will be amplified and the distribution of its components will be as represented by curve A_2 of Fig. 7. The degree of amplification is represented by G+P wherein G represents the gain corresponding to that of Fig. 3, and P represents a gain equal to the low frequency loss introduced by the predistortion network 4. It is necessary to provide the gain represented by G+P in order that the amplifier of Fig. 4 may be loaded up to approximately the same output level as the amplifier in the arrangement shown in Fig. 1. The curve C_1 of Fig. 7 represents the distribution of the harmonics created by the vacuum tubes of the amplifier 2. It will be seen that the curve C_1 at all frequencies, and particularly at the higher frequencies, is widely separated from the curve A_2. That situation is in striking contrast to the condition that is graphically set forth in Fig. 3 wherein the curve C so closely approaches curve B that the harmonics mask and distort the amplified wave. It will therefore be apparent, that by predistorting the envelope of the impressed wave, the tendency of the harmonics, generated by the vacuum tubes of the amplifier, to mask the high frequency components of the speech, music, or other material being transmitted over the system, is greatly reduced.

The output of amplifier 2 is impressed upon the restoring network 5 which network operates upon both the directly transmitted material as well as the wave representing the distortion effects created by the vacuum tubes. As shown in Fig. 8, the curves A_2 and C_1 (of Fig. 7) will be modified and will be as represented by B′ and C′. Curve B′ represents the distribution of the components of the directly transmitted material at the output of the restoring network and is similar in shape and magnitude to curve B of Fig. 3 since the restoring network has restored the various components to their original relative amplitudes. The high frequency harmonics produced by the vacuum tubes have also been reduced, as shown by curve C′ of Fig. 8.

It is evident from the foregoing description that by predistorting the directly transmitted material before impressing it upon the amplifier, and by restoring the output of the amplifier, to have the original distribution of relative amplitudes, the effect of the harmonics generated by the vacuum tubes, particularly throughout the high frequency range, will be considerably reduced, enabling the amplifier to operate at substantially the same rated output when associated with a loud speaker system having a wide frequency band as it would be with a loud speaker having a narrow frequency band.

The networks shown in Figs. 11 and 12 are of the same type as those described by Mr. Otto J. Zobel in his paper entitled "Distortion correction in electrical circuits with constant resistance recurrent network", that was published in July, 1928, in the Bell System Technical Journal, Vol. VII, No. 3.

The arrangement shown in Fig. 13, in which the same designating symbols have been employed as in Fig. 4, represents a system in which a plurality of amplifiers are spaced along the line connecting the predistortion and the restoring networks. Since the manner in which the arrangement shown in Fig. 13 functions is substantially the same as in Fig. 4, further description of Fig. 13 is deemed unnecessary.

The arrangements shown in the figures are schematic and it is to be understood that the invention is not limited except as defined by the appended claims.

What is claimed is:

1. In a system for reducing the distortion effects resulting from overloading a vacuum tube amplifier in a program transmission system, the combination with a line of an amplifier to be effectively connected between sections of said line, a predistortion network connected between a section of the line and the input terminals of the amplifier, the said network being designed to render substantially uniform the distribution with respect to frequency of the amplitudes of the components of the impressed wave, and a restoring network connecting the output terminals of the amplifier and an adjacent section of the said line, the transmission characteristic of the said restoring network being complementary to that of the predistortion network.

2. In a system for reducing the distortion effects resulting from overloading a vacuum tube amplifier in a program transmission system, the combination with an input circuit of a predistortion network capable of producing a loss in the amplitude of the wave impressed upon the amplifier by the input circuit, the said loss varying with frequency in approximately the same manner as the said amplitude varies with frequency, an amplifier upon which the predistorted wave is impressed, the said amplifier being adjusted so that the resultant wave will be substantially greater in amplitude throughout its entire frequency range than the wave representing distortion produced by said amplifier, and a restoring network connected with the output of the said amplifier capable of producing a loss in the output waves of the said amplifier, the said loss being the inverse of the loss produced by the predistortion network.

3. The method for reducing the distortion produced by vacuum tubes of an amplifier n a program transmission system, upon which amplifier a voltage wave is impressed, which consists in distorting the wave prior to amplification so that the energy content at each frequency will be substantially the same, amplifying the said wave as thus modified and then distorting the amplified wave in a manner inverse to the distortion effected prior to amplification.

4. The method for reducing the distortion of waves passing through an amplifier of a program transmission system as the result of harmonics created by the said amplifier, which consists in distorting the wave to be amplified prior to amplification, the degree of distortion being such that the amplitudes of the components of the distorted wave are substantially the same at all frequencies, amplifying the wave as thus distorted and modifying the waves resulting from the amplifying step, the character of the modification being such as to restore the distribution of the relative amplitudes of the components of the amplified wave to substantially the same distribution possessed by the wave prior to its predistortion, and also to reduce the harmonics created by the amplifier relatively to the components of the restored wave.

5. In a program transmission system, the combination with an input circuit, of an amplifier, an output circuit, a predistortion network connected between the input circuit and the input side of the amplifier, to substantially equalize the amplitudes of the components of the input wave, and a restoring network connected between the output side of the amplifier and the said output circuit, to give to the components of the amplified wave the same relative amplitudes as existed prior to predistortion.

In testimony whereof, I have signed my name to this specification this 9th day of September, 1930.

HAROLD S. HAMILTON.