DISTORTION NEUTRALIZING REPEATER

Filed Sept. 17, 1929 2 Sheets-Sheet 1

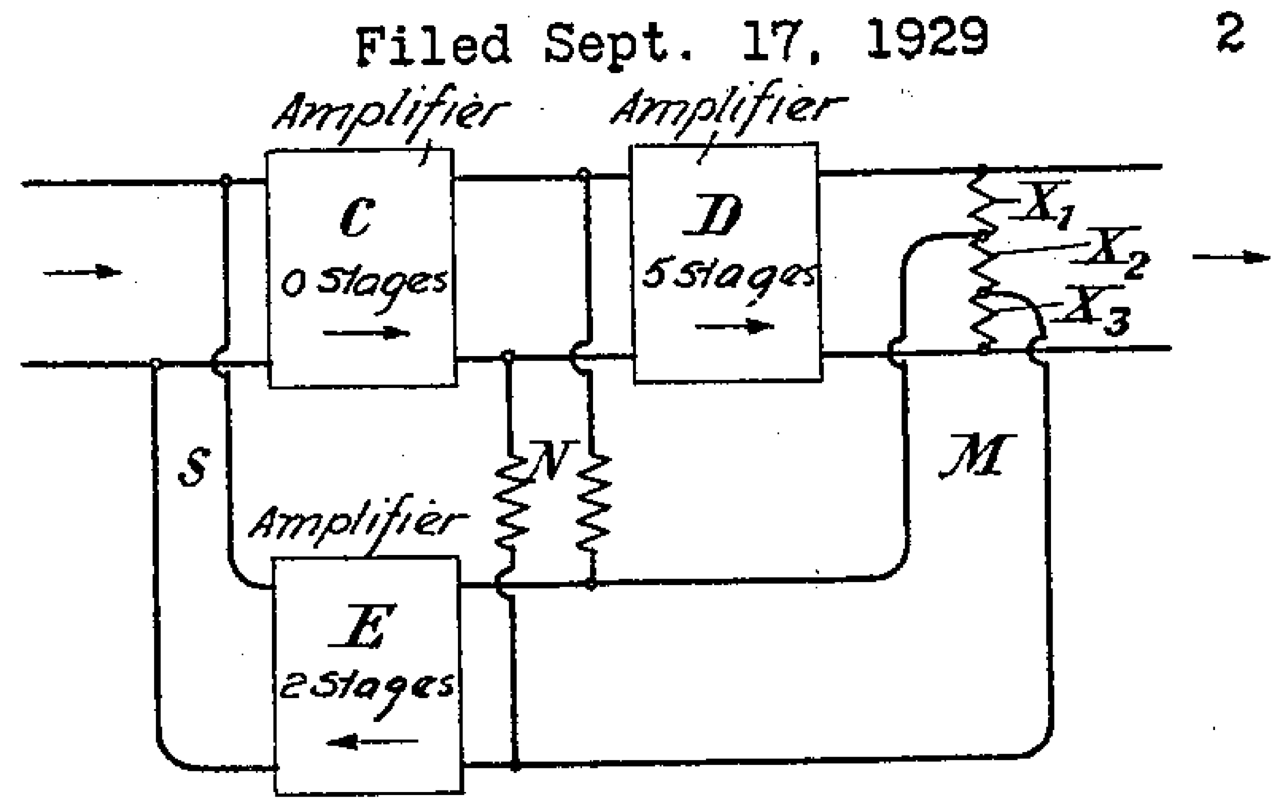

Fig. 1

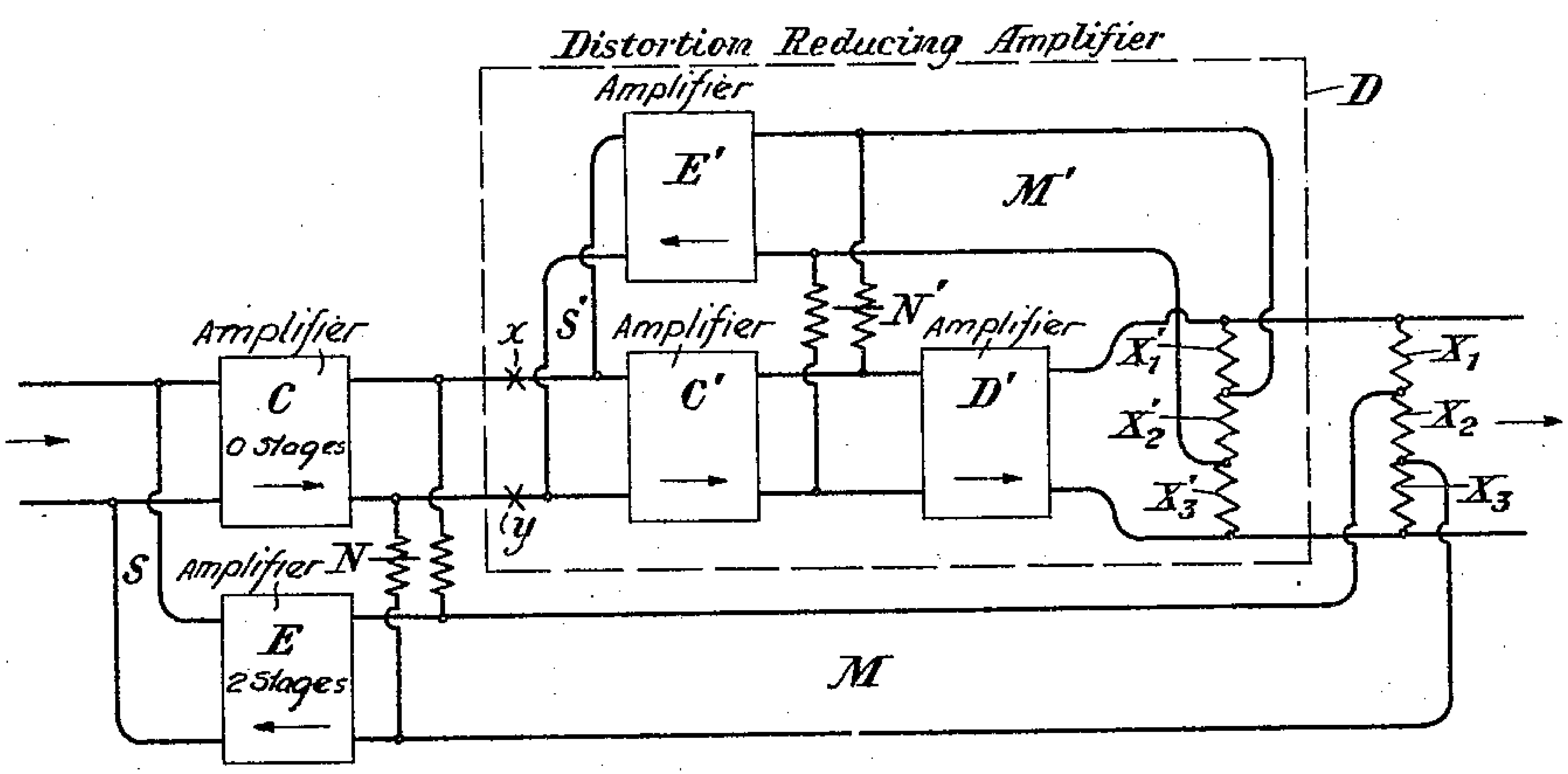

Fig. 2

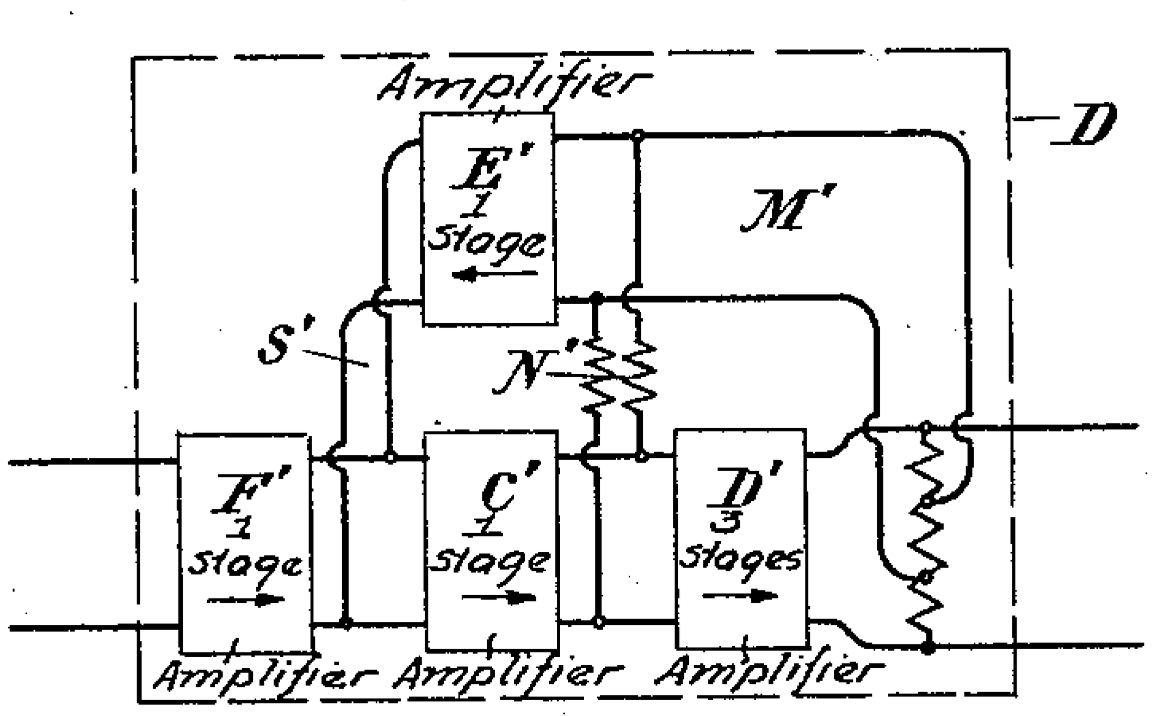

Fig. 3

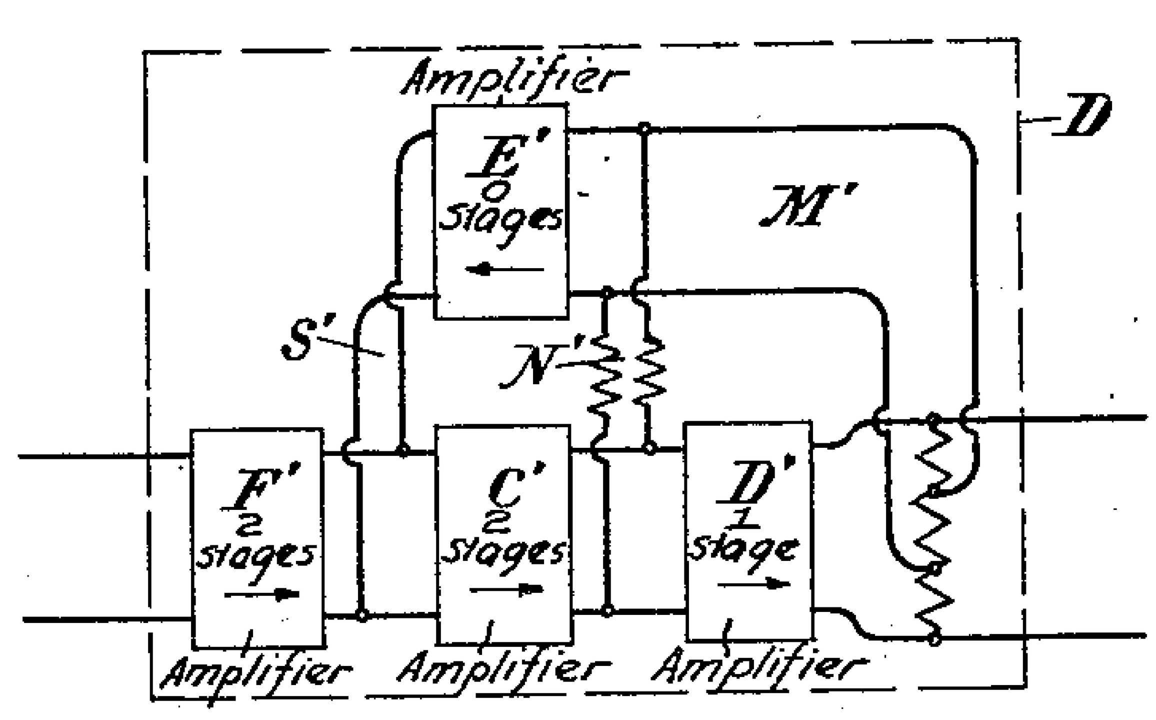

Fig. 4

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DISTORTION NEUTRALIZING REPEATER

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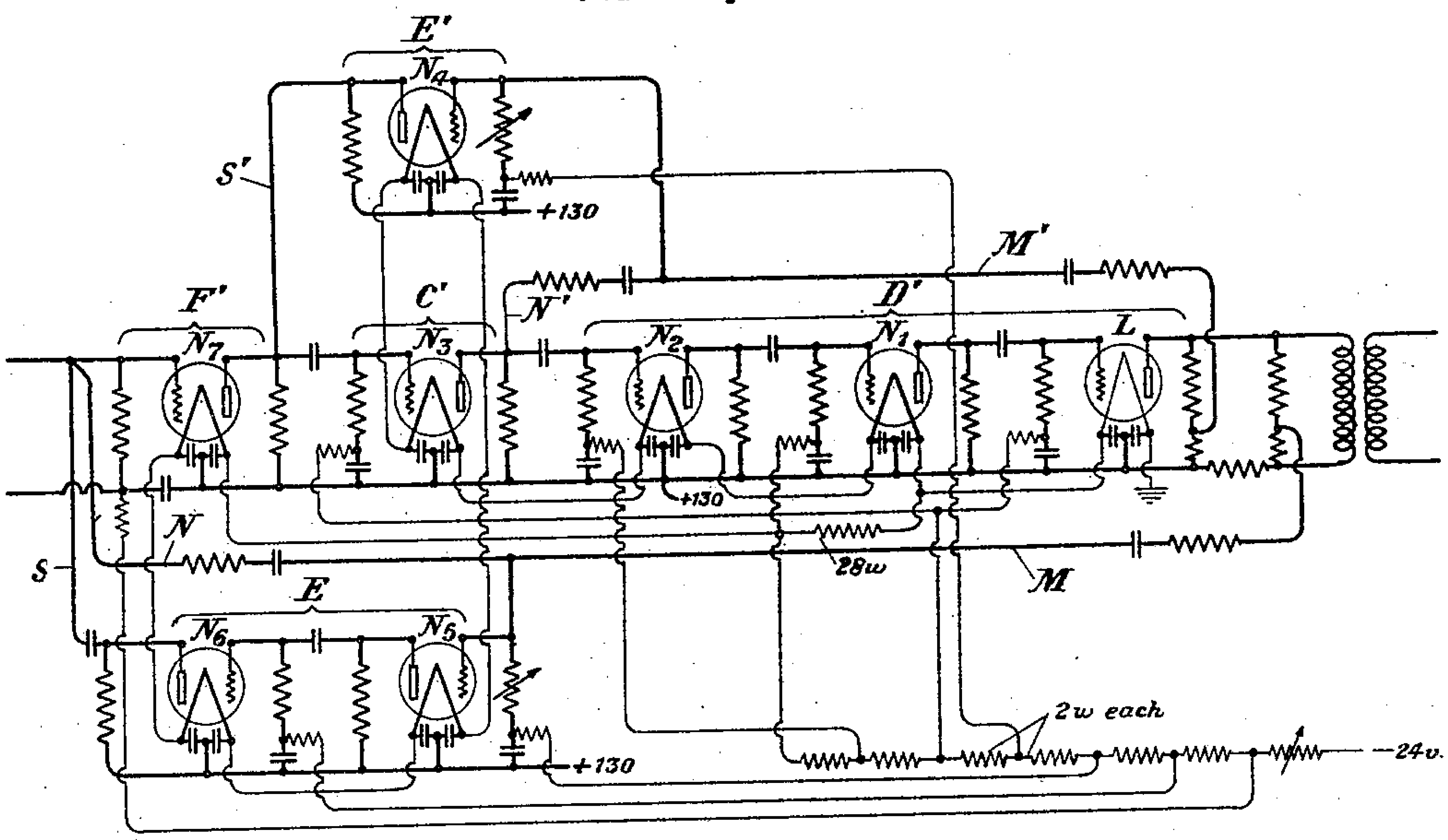

Fig. 3a

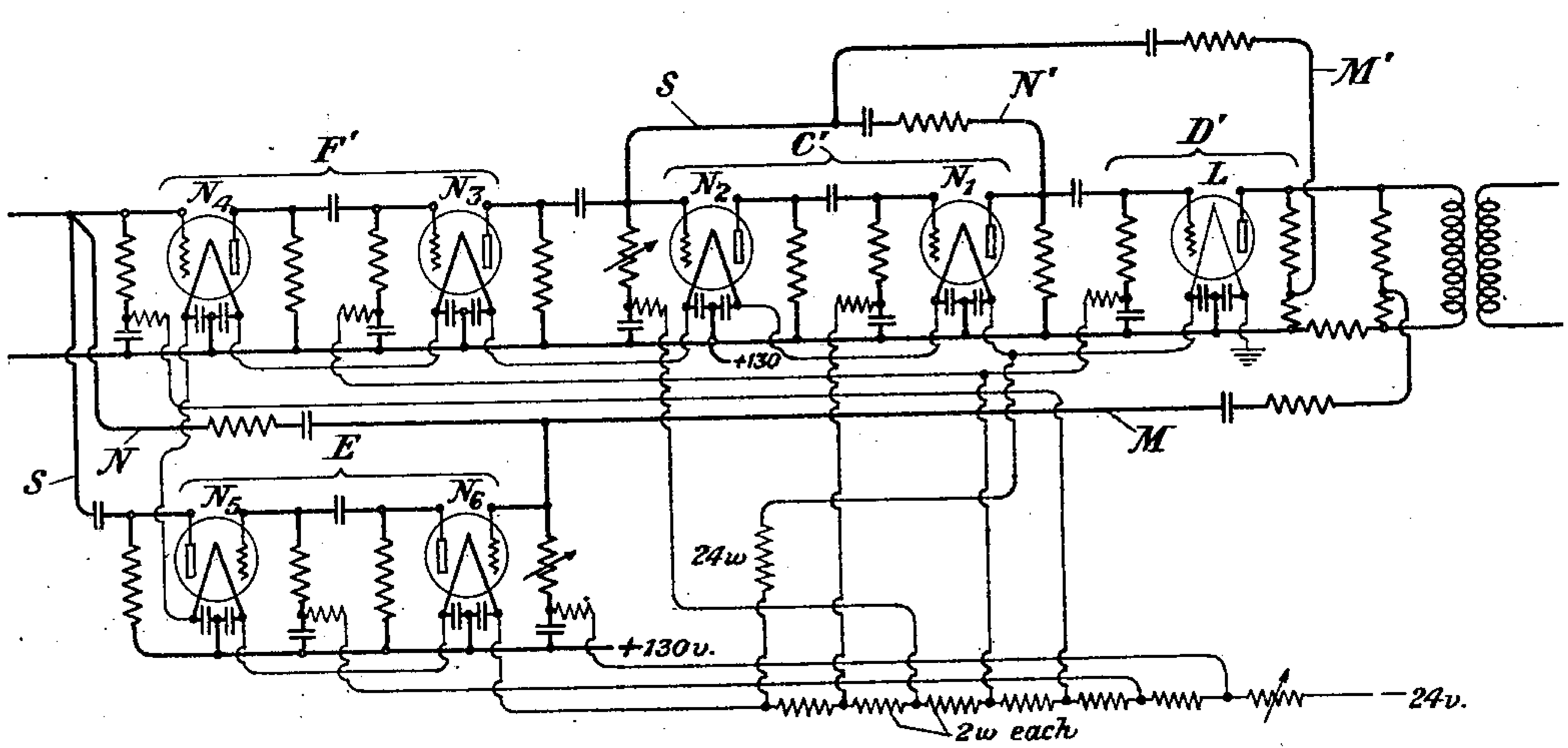

Fig. 4a

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UNITED STATES PATENT OFFICE

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DISTORTION NEUTRALIZING REPEATER

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This invention relates to wave translation systems, as for example, systems for amplifying electrical variations with the aid of electrical space charge devices, and more particularly it relates to improvements in such systems and in the circuit arrangements of the space charge device therein.

Repeaters have been proposed for neutralizing distortion by picking off some of the output wave from the output of an amplifier which distorts, neutralizing the undistorted portion of the wave thus picked off by means of an undistorted wave from the input of the amplifier, and then impressing the resultant wave which comprises distortion components only upon the input of the amplifier in such phase and amplitude as to neutralize the distortion due to the amplifier. Such a system, if it could be perfectly adjusted, would not only be substantially distortionless but would also compensate for variations in the gain of the amplifier due to variations of its circuit constants and would thus tend to maintain the gain uniform.

An arrangement, such as described, involves a repeater with a feed-back circuit of a special type and inherently the perfection of its operation depends upon the balance. Since it is impossible, in practice, to obtain a perfect degree of balance, it may happen that a repeater provided with a special feed-back arrangement of the type above described will not meet the requirements where a very high degree of freedom from distortion is necessary. Accordingly, it is proposed, in accordance with the present invention, to provide in a repeater of the type above described an amplifier of such character that the inherent distortion which must be balanced out will be reduced to the smallest possible limits. To accomplish this result, it is proposed to substitute for the ordinary multi-stage amplifier in such a repeater circuit a repeater that in itself is provided with a feed-back connection. The result is that the repeater includes a distortion neutralizing feed-back circuit within another distortion reducing feed-back circuit.

The invention will now be more fully understood from the following description when read in connection with the drawings in which Fig. 1 is a schematic diagram of a type of repeater to which the invention may be applied; Fig. 2 is a schematic diagram showing how the ordinary amplifier of a distortion neutralizing feed-back arrangement may be replaced by an amplifier which, in itself, is provided with a distortion reducing feed-back circuit; Figs. 3 and 4 are symbolic diagrams illustrating modifications of distortion reducing amplifiers which may be utilized in the circuit of Fig. 2 and Figs. 3 (*a*) and 4 (*a*) are diagrams showing in more detail circuit arrangements for carrying out the invention as embodied in Figs. 3 and 4, respectively.

A distortion neutralizing repeater of the type to which the present invention is to be applied is illustrated in Fig. 1 and comprises amplifier elements C, D and E connected by means of circuits M, N and S, as shown. In this type of repeater, the amplifying unit D is the principal amplifying unit for bringing the currents up to the desired large volume, the amplifying units C and E being worked at such low levels that the non-linear distortion due to their action may be neglected. Due to the high levels at which amplifier D must be worked, such amplifier, if of the ordinary multi-stage vacuum tube type, will have a certain amount of non-linear distortion which it is the function of the amplifiers C and E with their associated circuits M, N and S to compensate.

Let us assume that a pure sinusoidal wave is applied to the repeater of Fig. 1 and that the amplifier E is not functioning. A pure sinusoidal wave will then appear at the point between amplifiers C and D. On the output side of the amplifier D, a similar sinusoidal wave appears but it has superposed thereon certain distortion currents. By means of the resistance coupling X_1, X_2 and X_3, the circuit M picks off a portion of the output wave with its distortion and by means of the circuit N, the wave picked off is combined with a portion of the wave appearing between the amplifiers C and D. If care is taken that the phase and relative amplitudes of these two waves are properly related, the sinusoidal wave coming over the circuit N from the point between amplifiers C and D will just neutralize the sinusoidal part of the wave coming from the output of the amplifier D. As a result, the current which is applied to the input of the amplifier D is made up of distortion only. Now, if the amplifier E is made to function, this distortion will be introduced into the main circuit on the input side of the amplifiers C. Accordingly, it will be amplified by amplifiers C and D and will appear in the output. If care is taken to properly relate the amplitude and phase of this distortion current (which was applied to the circuit over the path S) to the phase and the amplitude of the distortion components of the sinusoidal wave after transmission through the amplifier D, this distortion may be made to neutralize the distortion generated in the amplifier D so that the ultimate output of the amplifier D will be an undistorted sinusoidal wave. On the other hand, if the gain in the amplifier E is made somewhat too great (or too small), the repeater will be made to over-correct (or under-correct) the distortion so that distortion generated in the amplifier C may be compensated, assuming, however, that the amplifier C has the same proportion of second and third harmonics as the amplifier D.

A repeater such as above described has another desirable property in that it tends to compensate for variations in gain. For example, suppose the gain in amplifier D changes, for some reason, such as a variation in battery voltage. As a result, the fundamental wave is not completely neutralized before entering amplifier E. In other words, a portion of the fundamental wave is amplified by the amplifier E as well as the distortion. The net result of this fundamental wave component when applied to the amplifier D is to keep the output in the line constant. For example, if the fundamental component coming from the circuit M is greater than that coming from the circuit N, the resultant wave passing through the amplifier E will be in such phase as to oppose the excess transmitted from the output of the amplifier D to the circuit M. On the other hand, if the fundamental component coming from the circuit M is smaller than that coming from the circuit N, the phase of the resultant wave passing through the amplifier E will be such as to add to the fundamental component appearing in the output circuit of the amplifier D. In other words, the circuit not only tends to keep the distortion zero but tends to keep variations in the gain of the amplifier D from having any effect on the overall gain.

In order to get proper functioning with this type of apparatus, it is necessary that the phase relations between the various waves be approximately right. This leads to the following requirements: (1) The amplifiers C, D and E must be resistance coupled or very nearly so. (2) The total number of the stages in amplifier D must be an odd number. (3) The total number of the stages in amplifier E plus amplifier C must be an even number.

Any number of stages may be used in the amplifiers C, D and E, subject to the foregoing requirements, depending upon the desired gain. Obviously, stages may be taken from the amplifier D and added to C so long as the number in D remains odd and the sum of the stages in C and E is even. There is a distinct disadvantage in this, however, in that the stages in the amplifier C will not be within the compensated portion of the circuit. Therefore, any distortion generated in these stages would be imperfectly compensated. Furthermore, variations in the gain of the amplifier C would not be properly compensated. On the other hand, the stages of the amplifier C may all be embodied in the amplifier E provided the number of stages is even. On the whole, the preferred design would apear to be a limited even number of stages in amplifier E and the necessary odd number of stages in amplifier D, with the amplifier C eliminated entirely so that the paths S and N will be bridged together across the input circuit of the amplifier D. In Fig. 1 of the drawings, a specific design is indicated in which five stages are employed in amplifier D and two stages in amplifier E with no stages in amplifier C, these conditions being indicated by the numerals below the letters indicating the amplifiers.

In the foregoing discussion of the operation, it is assumed conditions are ideal and where certain components are to be neutralized or balanced out, the conditions of balance will be perfect. In actual practice, however, these conditions do not obtain and some distortion will appear in the output of the repeater even with the neutralizing feed-back combination MNSE provided. For example, the amplifier D may be looked upon as inherently introducing a certain amount of non-linear distortion which is, say, N decibels below the main transmission. The feed-back apparatus shown in the figure may be thought of as reducing this distortion by an amount, say, N′ decibels. The total effect is that the resultant distortion is down by N+N′ decibels from the main transmission. Now, suppose, we have an operating condition which requires that N+N′ should equal 75. Under the best conditions of balance, the feed-back arrangement might be incapable of making a reduction in distortion such that N′ would be larger than 35. In order to meet the required condition, it would be necessary for the amplifier D to be sufficiently distortionless so that the value of

N would not be less than 40, a condition which is difficult of attainment by the use of ordinary amplifiers.

In order to overcome this difficulty, it is proposed, in accordance with the present invention, to reduce the distortion introduced by the amplifier D of Fig. 1 by making the amplifier D in the form of a repeater with a distortion neutralizing network of the type heretofore considered. The most obvious application of this idea would then take the form illustrated in Fig. 2. Comparing this arrangement with that of Fig. 1, it will be seen that the amplifier D of Fig. 2 instead of being a straightforward multi-stage amplifier will now in itself assume the form of a distortion neutralizing repeater involving the main amplifier D′, auxiliary amplifiers C′ and E′ with associated feed-back connections M′, N′ and S′. These elements all tend to function in the manner already described, with the result that the apparatus comprehended within the dotted rectangle D will in itself tend to reduce the normal distortion due to the operation of the amplifier D′, this distortion being further reduced by the normal feed-back arrangement comprising circuits M, N and S together with auxiliary amplifiers C and E.

If, however, the circuit of Fig. 2 is considered more critically, it becomes evident that there exists a difference between the type of amplifier shown within the dotted lines D and the ordinary one-way multi-stage amplifier. Whereas an ordinary one-way amplifier does not transmit any wave backward from its output to its input, the arrangement within the dotted lines D does return such a wave as a result of current delivered by amplifier E′. With a circuit arrangement such as shown in Fig. 2, some of this current would find its way into the amplifier E over the path N and thus upset the neutralization which would normally be expected to result from the use of the feed-back circuit M. In order to prevent such false action of the circuit shown in Fig. 2, it is necessary to prevent transmission in the reverse direction at the points *x—y*.

This may be accomplished by introducing a one-way device such as an amplifier at the points *x—y* so that transmission cannot take place from S′ to circuit N. With the introduction of such a one-way device, the apparatus comprised within the rectangle D may take the form indicated in Fig. 3, where a one-way device F′ is connected ahead of the circuit S′, as indicated.

If, now, the arrangement D of Fig. 3 be considered in connection with the circuit of Fig. 1, it will be seen that, in accordance with the design shown in Fig. 1, amplifier D should comprise five stages. In Fig. 3, these five stages are split up between the amplifying elements F′, C′ and D′, the total number of stages in these three amplifiers being an odd number, therefore conforming to the requirement (2) for amplifier D, as previously laid down. The number of stages in the amplifier D′ must also be an odd number for the same reason as given for the amplifier D, which means that the total number of stages in F′ and C′ must be an even number. In accordance with requirement (3) previously laid down for the arrangement of Fig. 1, it follows that the total number of stages in amplifiers C′ and E′ must be an even number. These various requirements are satisfied by the design in Fig. 3 (in which the number of stages in each amplifier is indicated by the numeral below the letter designating the amplifier) where the amplifiers F′, C′ and E′ are of one stage each and amplifier D′ comprises three stages. The resultant amplifier, corresponding to the amplifier D of Fig. 1, requires, in effect, only one additional amplifier tube, namely, that of the one stage amplifier E′.

A slightly different design for the amplifying apparatus within the rectangle D is illustrated in Fig. 4. Here the foregoing design requirements are satisfied by making amplifiers F′ and C′ of two stages each; amplifier D′ of one stage; while no stages are comprised within the amplifier E′. It will be seen that the total stages in F′, C′ and D′ is an odd number. D′ itself comprises an odd number and the total number of stages in amplifier E′ and C′ comprises an even number. This arrangement has the advantage that it provides a substitute for the amplifier D of Fig. 1, which utilizes only five stages of amplification and still provides a neutralizing feed-back arrangement for reducing the distortion. However, it has the disadvantage, as compared to Fig. 3, that only the distortion due to the one stage amplifier D′ is compensated. While it is true that by means of over-compensation or under-compensation it is possible to take care of the other stages (F′ and C′) in part, nevertheless, this arrangement, in this respect, would be somewhat inferior to that of Fig. 3. It is one which might be preferred to it, however, where greater simplicity is desired than in the case of Fig. 3.

Various other combinations of stages are possible but the arrangements shown in Figs. 3 and 4 are sufficiently illustrative of the principle so that it is deemed unnecessary to illustrate other modifications which will obviously suggest themselves.

The schematic arrangement shown in Fig. 3 is illustrated in more detail in Fig. 3 (*a*). As will be seen, the output of the three-stage amplifier D′ is connected by means of a feed-back circuit M′ to the input of the auxiliary one-stage amplifier E′. The output of the one-stage amplifier C′ is also connected to the input of the amplifier E′ whose output, in turn, is connected by means of S′ to the input of the one-stage amplifier C′, with the result that this combination of devices will function as a distortion reducing amplifier, performing the function of amplifier D of Fig. 1. The output of this amplifier arrangement is connected by means of a feed-back connection M to the input of the two-stage auxiliary amplifier E whose input is also connected by the path N to the input of the system. The output of the amplifier E is also connected by path S to the input of the system.

In the design shown in Fig. 3 (*a*), the last stage of the amplifier D′ may comprise a so-called L tube while the other stages are made up of so-called N tubes. The filament drop of the N tube is about one volt while that of the L tube is about 4 volts. For proper operation the grid of the N tube should be biased about 6 volts more negative than its filament while the L tube should have its grid potential about 9 volts negative with respect to the filament. The circuit is so arranged that the filaments of all of the tubes are connected in series, as will be clear from an inspection of the drawing, and the biasing potentials for the grids of the various tubes may be taken from taps in the filament supply circuit. In order to accomplish this result, a number of resistances of about two ohms each are provided in the filament supply circuit so that the drop is about equivalent to that through an N tube filament. A 28-ohm resistance is shunted across the filaments of the various N tubes to take care of the fact that the filament current for an N tube is only ¼ ampere as compared with a ½ ampere for the L tube. If the connections from the grid to the various tubes in the filament supply circuit be traced, it will be found that the grid of each N tube will be connected to a point in the filament supply circuit biased 6 volts more negative than the negative side of its filament while the L tube will have its grid connected to a point about 9 volts negative with respect to its filament. In analyzing these connections, it should be remembered that filaments of the tubes are connected in the following order: Tube L followed by the tubes N_1 and N_2 of the amplifier D′, then tube N_3 of amplifier C′, tube N_4 of amplifier E′, tubes N_5 and N_6 of amplifier E and finally the tube N_7 of the amplifier F′.

The schematic arrangement of Fig. 4 is also shown in more detail in Fig. 4 (*a*). Here the amplifier D′ comprises a single L tube designated L. The amplifier E′ is eliminated and the amplifier C′ comprises two N tubes. The one-way device F′ also comprises two N tubes as does the auxiliary amplifier E of the main circuit. Analysis of this circuit arrangement shows that it conforms to the schematic layout of Fig. 4 and will therefore operate in the manner previously described. Here, again, the filaments of all of the tubes are connected in series in the same filament supply circuit and the potentials of the grids are obtained from taps in the filament supply circuit for which purpose a number of two-ohm resistances are connected in series, each of which will have a drop about equivalent to that through the filament of one N tube. By tracing the connections of the various grids to the various taps in the filament supply circuit, it will be seen that the grid of the L tube is 9 volts negative with respect to its filament and the grid of each N tube is biased negative about 6 volts. In tracing these connections it should be borne in mind that the filaments of the tubes are connected in the following order. First, the tube L_1, then N tubes N_1 and N_2 of amplifier C′, followed by the two N tubes of amplifier F′ which are in turn followed by the tubes N_5 and N_6 of the auxiliary amplifier E.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a distortion neutralizing repeater, a main amplifying arrangement including a principal amplifier, an auxiliary amplifier, a feed-back connection from the output of said principal amplifier to the input of said principal amplifier, and a connection from the input of said principal amplifier to the input of said auxiliary amplifier; a second auxiliary amplifier, a feed-back connection from the output side of said main amplifying arrangement through said second auxiliary amplifier to the input side of said main amplifying arrangement, and a connection from the input side of said main amplifying arrangement to the input of said second auxiliary amplifier.

2. In a distortion neutralizing repeater, a main amplifying arrangement including a principal amplifier, an auxiliary amplifier, a feed-back connection from the output of said principal amplifier through said auxiliary amplifier to the input of said principal amplifier, and a connection from the input of said principal amplifier to the input of said auxiliary amplifier; a second auxiliary amplifier, a feed-back connection from the output side of said main amplifying arrangement through said second auxiliary amplifier to the input side of said main amplifying arrangement, a connection from the input side of said main amplifying arrangement to the input of said second auxiliary amplifier, and means to prevent transfer of energy from said first-mentioned feed-back connection over said last-mentioned connection to said second auxiliary amplifier.

3. In a distortion neutralizing repeater, a

main amplifying arrangement including a principal amplifier, an auxiliary amplifier, a feed-back connection from the output of said principal amplifier through said auxiliary amplifier to the input of said principal amplifier, and a connection from the input of said principal amplifier to the input of said auxiliary amplifier; a second auxiliary amplifier, a feed-back connection from the output side of said main amplifying arrangement through said second auxiliary amplifier to the input side of said main amplifying arrangement, a connection from the input side of said main amplifying arrangement to the input of said second auxiliary amplifier, and a one-way device interposed between said first-mentioned feed-back connection and said last-mentioned connection to said second auxiliary amplifier, said device being so poled as to prevent transmission from the former connection to the latter connection.

4. In a distortion neutralizing repeater, a main amplifying arrangement including a principal amplifier, an auxiliary amplifier, a feed-back connection from the output of said principal amplifier through said auxiliary amplifier to the input of said principal amplifier, and a connection from the input of said principal amplifier to the input of said auxiliary amplifier; a second auxiliary amplifier, a feed-back connection from the output side of said main amplifying arrangement through said second auxiliary amplifier to the input side of said main amplifying arrangement, a connection from the input side of said main amplifying arrangement to the input of said second auxiliary amplifier, and a vacuum tube amplifier interposed between said first-mentioned feed-back connection and said last-mentioned connection to said second auxiliary amplifier, said vacuum tube amplifier being so poled as to prevent transmission from the former connection to the latter connection.

5. In a distortion neutralizing repeater, a principal amplifier, an input connection thereto, a first auxiliary amplifier, a feed-back connection through said first auxiliary amplifier to the input of said principal amplifier, a neutralizing connection from the input of said principal amplifier to said feed-back connection to produce at least partial neutralization of components of waves fed back corresponding to the input wave; a second auxiliary amplifier, a second feed-back connection from the output side of said principal amplifier through said second auxiliary amplifier to the input side of said principal amplifier, and a second neutralizing connection from the input side of said principal amplifier to said second feed-back connection to at least partially neutralize components of waves fed back over said second feed-back and corresponding to waves applied to the input side of said principal amplifier.

6. In a distortion neutralizing repeater, a principal amplifier, an input connection thereto, a first auxiliary amplifier, a feed-back connection through said first auxiliary amplifier to the input of said principal amplifier, a neutralizing connection from the input of said principal amplifier to said feed-back connection to produce at least partial neutralization of components of waves fed back corresponding to the input wave; a second auxiliary amplifier, a second feed-back connection from the output side of said principal amplifier through said second auxiliary amplifier to the input side of said principal amplifier, a second neutralizing connection from the input side of said principal amplifier to said second feed-back connection to at least partially neutralize components of waves fed back over said second feed-back and corresponding to waves applied to the input side of said principal amplifier, and means to prevent transfer of energy from said first feed-back connection to said second neutralizing connection.

7. In a distortion neutralizing repeater, a principal amplifier, an input connection thereto, a first auxiliary amplifier, a feed-back connection through said first auxiliary amplifier to the input of said principal amplifier, a neutralizing connection from the input of said principal amplifier to said feed-back connection to produce at least partial neutralization of components of waves fed back corresponding to the input wave; a second auxiliary amplifier, a second feed-back connection from the output side of said principal amplifier through said second auxiliary amplifier to the input side of said principal amplifier, a second neutralizing connection from the input side of said principal amplifier to said second feed-back connection to at least partially neutralize components of waves fed back over said second feed-back and corresponding to waves applied to the input side of said principal amplifier, and a one-way device so connected as to prevent transfer of energy from said first feed-back connection to said second neutralizing connection.

8. In a distortion neutralizing repeater, a principal amplifier, an input connection thereto, a first auxiliary amplifier, a feed-back connection through said first auxiliary amplifier to the input of said principal amplifier, a neutralizing connection from the input of said principal amplifier to said feed-back connection to produce at least partial neutralization of components of waves fed back corresponding to the input wave; a second auxiliary amplifier, a second feed-back connection from the output side of said principal amplifier through said second auxiliary amplifier to the input

side of said principal amplifier, a second neutralizing connection from the input side of said principal amplifier to said second feed-back connection to at least partially neutralize components of waves fed back over said second feed-back and corresponding to waves applied to the input side of said principal amplifier, and a vacuum tube amplifier so connected and so poled as to prevent transfer of energy from said first feed-back connection to said second neutralizing connection.

In testimony whereof, I have signed my name to this specification this 13th day of September 1929.

HARRY NYQUIST.