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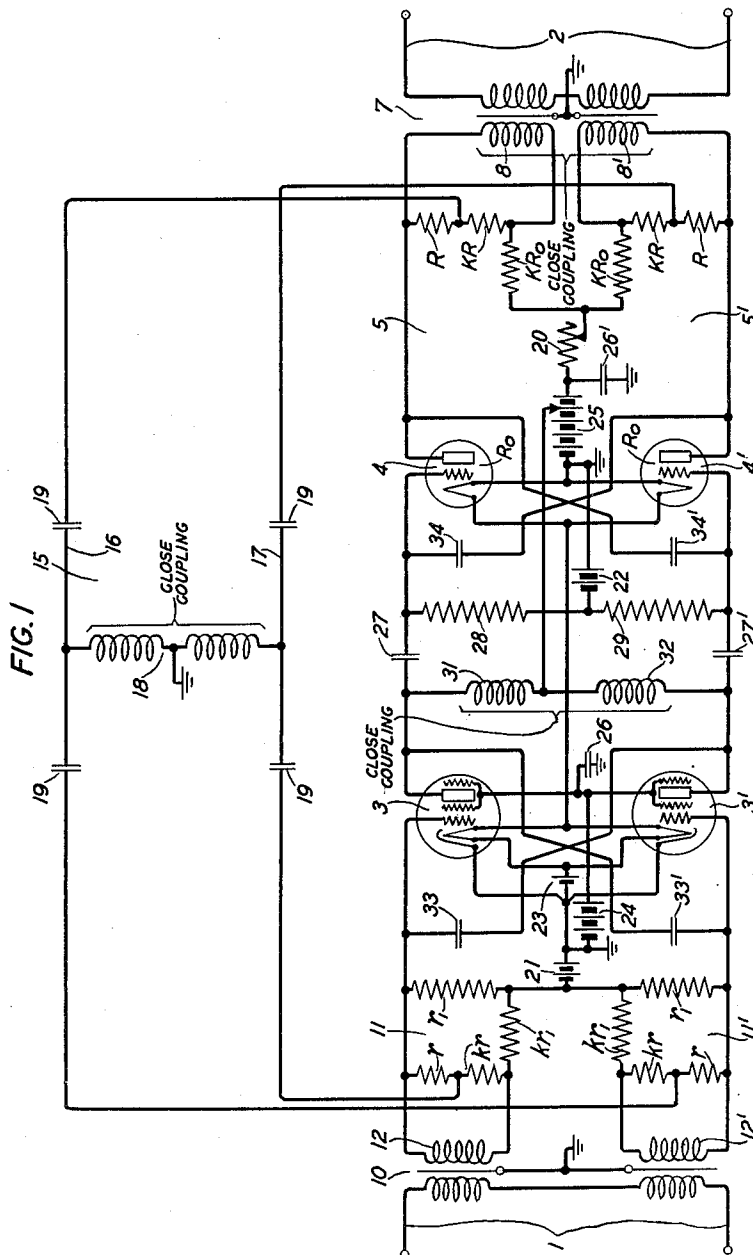
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1,955,827

WAVE TRANSLATING SYSTEM

Filed June 16, 1932

2 Sheets-Sheet 1



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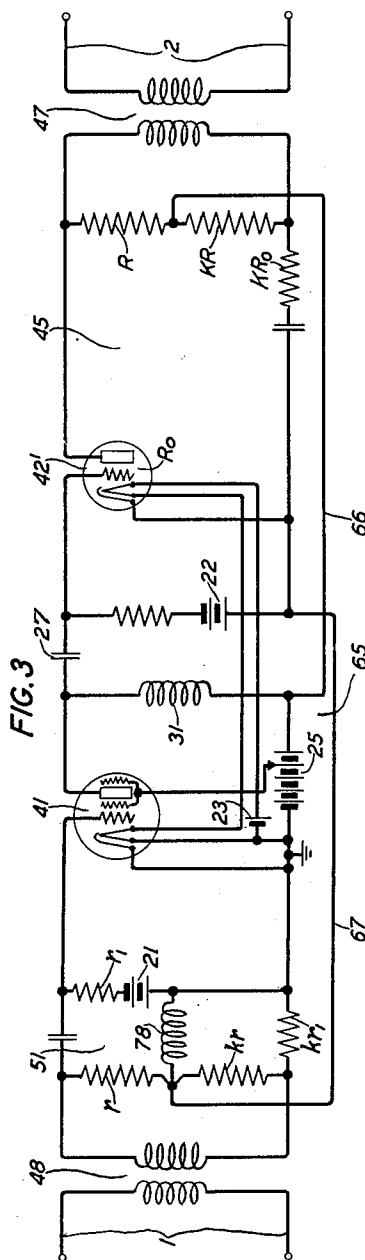
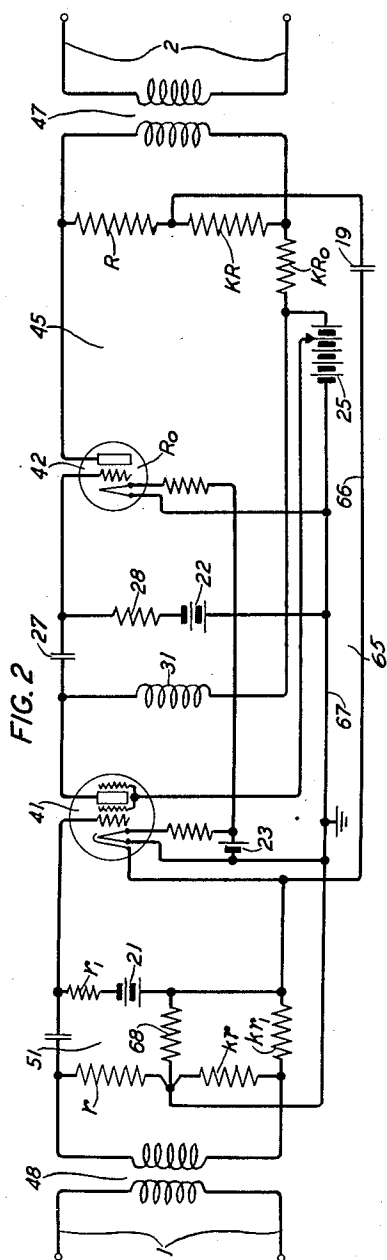
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UNITED STATES PATENT OFFICE

1,955,827

WAVE TRANSLATING SYSTEM

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Application June 16, 1932, Serial No. 617,557

8 Claims. (Cl. 179—171)

This invention relates to wave translating systems, as for example, vacuum tube amplifiers.

Representative objects of the invention are to control transmission properties of such systems, for example, with respect to amplitude relations or wave form. Illustrative specific objects are to control amplification, gain (a measure of absolute value of amplification), distortion or change in wave form (for instance, non-linear distortion or phase distortion), and stability of transmission (for instance, stability of amplification or of gain).

Certain features of the invention relate to attainment of such objects by retroaction or feedback in the system.

In such systems waves can be so fed back, as explained for example in the copending application of H. S. Black, Serial No. 606,871, filed April 22, 1932, Wave translation systems, assigned to the assignee of this application, as to reduce unwanted modulation or non-linear effects and to render the gain stability greater than it would be without feedback.

In such systems phase shifts in the closed feedback loop may produce objectionable singing tendencies. It is often desirable to use an odd number of vacuum tube stages or of other phase reversing means to facilitate control of the singing tendencies. However, when the gain, without feedback, required in order to obtain the desired amount of stabilizing or distortion reducing feedback and the desired amount of gain with feedback, necessitates use of a plurality of stages and a plurality of interstage coupling circuits, the phase shifts around the closed loop may become large at both low and high frequencies, usually at frequencies well below or above the utilized range. At the low frequencies, interstage coupling condensers may be responsible for large phase shift while at high frequencies the phase shift may again become large because of tube and wiring capacities. The singing tendency may become particularly marked when the grids are driven positive especially when the amplifier is called upon to transmit wide frequency bands extending to very low or to very high frequencies. These difficulties can be reduced by carefully proportioning of the circuit elements to permit large phase shift only where the gain is reduced below the singing point. It frequently becomes difficult to adapt transformer interstage coupling to feedback amplifiers because of the large phase shifts associated with small gain changes.

In one specific aspect the invention is a feedback circuit of the general type referred to above employing an even number of vacuum tube stages, for example two stages, with the desired feedback phase obtained by reversing leads in either the coupling or feedback circuits. This reversing of the leads crosses them from one side to the other side of the push-pull circuit. Where the amount of gain desired exceeds that obtainable with this two-stage amplifier, a plurality of these two-stage amplifiers can be connected in tandem. In a single line (unbalanced) amplifier the desired result can be obtained by reversing the feedback circuit leads or the leads in the interstage coupling circuit with respect to the cathodes. In this case some feedback exists in each stage, in addition to the feedback associated with the amplifier as a whole. Also, in this case the cathodes are at different potentials and, to facilitate use of a common filament current supply, at least one tube may be of the heater type.

The push-pull circuit described above is especially advantageous in that the balance of the circuit reduces even order modulation products, so that for a given distortion reduction, only a part need be produced by gain-reducing feedback. Thus, the balance can render the use of two stages feasible where without distortion reduction produced by balance the amount of gain reduction required for the desired distortion reduction would necessitate use of more than two stages which, in turn, might produce objectionable increase of singing tendency due to the increased number of circuit elements such as tube capacities and interstage coupling circuits.

In one specific aspect the invention is a vacuum tube circuit in which gain and gain variation and distortion are reduced by feedback as referred to above, and the transmission efficiency of the circuit is increased by also feeding back waves which neutralize shunting effects of the tube and circuit capacities in the general manner disclosed in United States patent to C. W. Green, No. 1,668,240, May 1, 1928.

A feature of the invention relates to control of third order products of a vacuum tube by feedback of second order product, or to a feedback stabilized vacuum tube circuit in which the impedance of the external circuit of the tube is adjusted to an optimum value with respect to suppression of third order, or second order and third order, modulation products. As explained in the copending application of J. G. Kreer, Jr.,

Serial No. 595,502, filed February 27, 1932, for Reduction of distortion in vacuum tube circuits, assigned to the assignee of this application, the magnitude of the third order modulation products of a vacuum tube operating as an amplifier depends upon the second order output (and therefore on the external impedance to second order products). However, it has further been found that with negative (i. e. gain-reducing) feedback, the third order output will depend not only upon the reduction of third order output obtained by negative feedback of third order, but further will depend on the reduction of second order output obtained by negative feedback of second order, and that this negative feedback of second order products can either increase or decrease the magnitude of third order output (i. e. render it greater or less than if there were no feedback of second order), or leave it unaffected, in accordance with the value of the external impedance to second order products. (Under certain conditions the negative feedback of second order products can even increase the third order output, for a given output of fundamental, more than the negative feedback of third order products reduces the third order output, even when the transmission properties of the path around the feedback loop are the same for the frequencies concerned.) In one specific aspect the invention is a feedback stabilized push-pull vacuum tube amplifier in which the impedance of the common branch in the tube output circuits for second order products of modulation is adjusted for maximum suppression of third order products, or in which the external impedances of the tube output circuits are made low, to insure desired suppression of third order output by feedback action in the amplifier.

It has been found that in the case of a feedback stabilized type of balanced or push-pull amplifier, the feedback connections employed to produce stability or fidelity of amplification may give rise to parallel singing in the circuit; and in accordance with the invention means is provided forming a low impedance shunt path for the parallel singing path but a high impedance shunt for the feedback loop path.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 shows a push-pull or balanced amplifier embodying one form of the invention;

Fig. 2 shows a single line amplifier or single string amplifier embodying another form of the invention; and

Fig. 3 shows a modification of the amplifier of Fig. 2.

Fig. 1 shows a two-stage push-pull amplifier for amplifying waves received from circuit 1 and transmitting the amplified waves to circuit 2. The first stage comprises two similar vacuum tubes 3 and 3', shown by way of example as heater type screen-grid tubes. The second stage comprises two tubes 4 and 4' which are also alike and which are shown, by way of example, as three-element tubes.

The tubes 4 and 4' are connected to the outgoing circuit 2 through two bridge networks 5 and 5' and output transformer 7. The transformer has two primary windings 8 and 8'. The winding 8 forms one diagonal of the bridge circuit 5; and the winding 8' forms one diagonal of the bridge circuit 5'. The four ratio arms of bridge circuit 5 comprise four resistances R_o , KR_o , KR and R , respectively, the resistance R_o

being the plate-cathode resistance in tube 4. The four ratio arms of bridge circuit 5' likewise comprise four resistances R_o , KR_o , KR and R , of which the resistance R_o is the plate-cathode resistance in tube 4'.

The incoming circuit 1 is connected to the tubes 3 and 3' through input transformer 10 and two bridge networks 11 and 11'. The transformer 10 has two secondary windings 12 and 12'. The winding 12 forms one diagonal of the bridge circuit 11; and the winding 12' forms one diagonal of the bridge circuit 11'. The four ratio arms of the bridge circuit 11 comprise resistances r_1 , kr_1 , kr and r , respectively, the grid and cathode of tube 3 being connected across arm r_1 . The four ratio arms of bridge circuit 11' likewise comprise four resistances r_1 , kr_1 , kr and r , the grid and cathode of tube 3' being connected across this resistance r_1 .

A feedback path or circuit 15 connects the output circuit of the amplifier to the amplifier input circuit, the feedback through this path rendering the amplifier more stable than it would be without feedback and reducing distortion produced by the amplifier. The path 15 comprises two conductors 16 and 17, a closely coupled retard coil or inductance coil 18 connected across conductors 16 and 17 and having its mid-point connected to the grounded cathode system of the amplifier to prevent parallel singing, and stopping or blocking condensers 19 each of large capacity, for example, a few microfarads. Parallel singing tends to result from feedback transmitted longitudinally through the feedback circuit with the tubes operating as two unbalanced amplifiers in parallel. With an even number of stages in the balanced amplifier, a considerable loss should be introduced in the parallel singing path to prevent this parallel singing, the required amount of loss depending upon the gain around the feedback circuit. The coil 18, with its close coupling, is a low impedance shunt across the path for this parallel singing, yet presents high impedance to current flow in series through the two halves of the coil.

With the two-stage balanced amplifier, feedback for distortion reduction and for stabilization is obtained in the desired phase by reversing the feedback leads 16 and 17, i. e., crossing them over from one side of the push-pull circuit to the other side. Thus, lead 16 is connected from the bridge circuit 5 in the output circuit of tube 4 (which is in the upper side of the push-pull circuit) to the bridge circuit 11' in the input circuit of tube 3' (which is in the lower side of the push-pull circuit); and lead 17 is similarly connected between the output bridge circuit 5' or tube 4' (which is in the lower side of the balanced circuit) to the input bridge circuit 11 of tube 3 (which is in the upper side of the balanced circuit).

As noted above, the winding 8 is in one diagonal of the bridge circuit 5 and the winding 8' is in one diagonal of bridge circuit 5'. The other diagonals of these bridge circuits are in series across the end of the feedback path 15 at the output side of the amplifier. As noted above, windings 12 and 12' are in diagonals of bridge circuits 11 and 11'. The other diagonals of these two bridge circuits are in series across the end of the feedback path 15 at the input side of the amplifier. Thus, the bridge circuits 5, 5', 11 and 11' render the feedback path conjugate to the incoming circuit 1 and the outgoing circuit 2, and consequently the phase shift of the feedback

voltage can be determined principally by the tubes and their associated coupling and will be independent of the impedances of the incoming circuit and the outgoing circuit.

5 Windings 8 and 8' are closely coupled. This reduces the external impedance encountered by second order products generated in tubes 4 and 4'. With perfect coupling and with perfect sym-
10 metry of the two sides of the push-pull circuit (including identity of transmission properties of the balanced tubes), this impedance is (merely) twice that of the common branch or mid-branch of the output circuit of these tubes 4 and 4', plus one of the impedances KR_o in the case
15 of each tube. Making the external impedance encountered by the second harmonic low has been found to facilitate suppression of third harmonic by the feedback action. Regarding the theory of operation of a single-stage amplifier, while nega-
20 tive feedback (i. e., gain-reducing feedback) reduces second order products of modulation (for a given output of fundamental) by the same amount that it reduces the gain for fundamental (assuming the transmission properties of the
25 path around the feedback loop to be the same for the frequencies concerned), it has been found that higher orders of modulation are not affected in the same way as is the second; for, as explained
30 for instance in the above mentioned copending application of J. G. Kreer, Jr., the magnitude of third order modulation products depends upon the second order output. With feedback, then, the third order output will depend not only on the reduction of third order output produced by
35 negative feedback of third order (which reduction is represented by the same factor or multiplier that represents the reduction of second order output), but further, will depend upon the reduction of second order output produced by negative
40 feedback of second order. It can be shown mathematically that, (with the transmission properties of the feedback loop the same for the frequencies concerned), under certain conditions negative feedback reduces the third order output
45 by a greater amount, and under certain other conditions by a smaller amount, than the loss to fundamental or the reduction in amplification of fundamental produced by the feedback; that under certain conditions the negative feedback
50 can increase the third order output; and that the only possibilities of having the reduction of third order equal the loss to fundamental are to have zero feedback for second orders or to have the
55 external impedance to second orders equal to zero. While these considerations have been occupied with a single-amplifier stage, the same general results are obtained in a multi-stage amplifier when the feedback has the proper phase.

Thus, by making the external impedance for
60 second harmonic produced in tubes 4 and 4' very low (which can be done by having windings 8 and 8' closely coupled and having the impedances KR_o small and keeping the impedance of the common branch of the output circuit of the tubes
65 low), the negative feedback action in the amplifier can definitely be made to reduce second and third order products. Moreover, if desired, the external impedance encountered by third order products generated in the tubes 4 and 4' can be
70 adjusted to obtain maximum suppression of third order products or optimum conditions of reduction of second and third orders, taking into consideration the fact that the external impedance for second order products, and the second order output, affects third order output as disclosed in

the above mentioned application of J. G. Kreer, Jr. For example, if desired an impedance, for instance, an adjustable resistance 20 can be inserted in the common branch of the output circuit of tubes 4 and 4', and adjusted by trial to
80 the optimum value for the desired suppression or control of third order products or of second and third order products.

As examples of biasing and energizing sources which may be employed for the amplifier there
85 are shown batteries 21 and 22 for supplying control grid biasing potentials, battery 23 for supplying filament heating current, battery 24 for supplying screen-grid potentials, and battery 25 for supplying plate potentials. By-pass condensers
90 26 and 26' are shown for the batteries 24 and 25, respectively.

The plate of tube 3 is connected to the grid of tube 4 through a stopping condenser 27; and, similarly, the plate of tube 3' is connected to the
95 grid of tube 4' through a stopping condenser 27'. Grid potentials are supplied to tubes 4 and 4' through high resistances 28 and 29, respectively. The direct space currents for tubes 3 and 3' are supplied through closely coupled choke coils 31
100 and 32, respectively. The close coupling reduces parallel singing in the manner explained above in connection with the two halves of coil 18, and moreover gives low impedance for second order products generated in tubes 3 and 3'.
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A condenser 33 connects the plate of tube 3' to the grid of tube 3; a condenser 33' connects the plate of tube 3 to the grid of tube 3'; a condenser 34 connects the plate of tube 4' to the grid of tube 4; and a condenser 34' connects the plate of tube
110 4 to the grid of tube 4'. The condensers 33 and 33' may be merely neutralizing condensers. On the other hand, they may be larger than would be required to merely annul inherent feedback from the second stage to the first stage, (i. e., feedback
115 other than the stabilizing feedback through path 15), so they will supply from the output of the first stage the current required by the amplifier input impedance, in the general manner disclosed in the above mentioned patent to C. W. Green.
120 This reduces the effective input capacity of the amplifier. This is especially important when the amplifier is to provide amplification over broad frequency bands extending for example up to 500,000 and 5,000,000 cycles where the shunting
125 effect of the capacity tends to limit the amplification obtainable, and is the more important because the gain is reduced by the stabilizing feedback through path 15. The condensers 34 and 34' may be merely neutralizing condensers. On the
130 other hand, they may be larger than would be required merely to annul inherent feedback and may function in connection with tubes 4 and 4' in the manner last described as a manner in which condensers 33 and 33' may function in connection
135 with tubes 3 and 3'. These condensers in the second stage have added importance because the power stage has relatively high shunt capacities compared to the first stage with its screen-grid tubes. The action of the condensers 33, 33',
140 34 and 34' to more than neutralize inherent feedback effects may be termed "over-neutralization". The increase of the capacities of these condensers beyond that required for neutralization of the incidental or inherent coupling between grid and
145 plate circuits by internal tube capacities and wiring results in the production of negative capacity across the input terminals of the tubes, which neutralizes the shunting effect of the wiring and element capacities associated with the tubes and
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the circuit. The negative capacity so produced is associated with a negative resistance, which tends to produce oscillation of the circuit at high frequencies, and which should not be allowed to reach such values, relative to the other circuit impedances, as to result in undesired oscillations.

Minimizing phase shift and modulation in an amplifier facilitates practical application of feedback to the amplifier for stabilization or distortion reduction. Among advantages of balance in a feedback-stabilized amplifier are: The reduction of even order modulation by the balance and the possibility of decreasing the third order modulation by adjusting the impedance to the second order, thereby requiring less (gain-reducing) feedback to satisfy a given modulation requirement; the ease of applying neutralization and over-neutralization with corresponding improvements in the gain at high frequencies, (neutralization and over-neutralization being readily obtainable without necessity of the neutralizing circuit interconnecting tubes separated by a coupling circuit and therefore over a wide frequency range); and finally the fact that the feedback circuit is balanced makes possible the introduction of feedback in either an odd or even number of stages. The last advantage is important in feedback-stabilized amplifiers not only because of the greater freedom permitted in design but also because, in cases in which the gain and modulation requirements can be met with two stages, phase shift difficulties encountered with the usual three-stage unbalanced amplifier can be avoided. This becomes of increasing importance at high frequencies due to shunt capacity and at very low frequencies due to blocking condensers.

In designing a wide band feedback amplifier, phase shift around the feedback circuit presents one of the principal limitations particularly at high frequencies. This phase shift may cause singing which can not be permitted at any frequency because of overloading; or it may cause an increase in the gain of the amplifier, which increase may be undesirable because accompanied by a corresponding increase in the modulation products. Phase shift in the feedback circuit may be reduced by decreasing the number of circuit elements or by decreasing the phase shift introduced by each element. In many cases the latter procedure is difficult particularly at high frequencies so that the balanced amplifier, having only two stages, has a decided advantage in this respect over a three-stage amplifier.

The increase in gain mentioned above does not necessarily become a limiting factor excepting at high frequencies where it becomes difficult to obtain sufficient feedback. For example, assuming that the amplifier does not sing, the change in gain of the feedback amplifier will be within one db of the gain around the feedback loop regardless of phase shift if the gain around the feedback loop is over 20 db. Furthermore, there will be no increase in gain due to the feedback if the gain around the feedback circuit is over 6 db.

At times, especially with a careful selection of tubes and coupling circuits, it is practicable to meet gain and modulation requirements with a two-stage balanced amplifier at high frequencies where phase shift would become an important limiting factor in the design of a three-stage unbalanced feedback amplifier. The balanced amplifier will then have a decided advantage because the feedback circuit will include only one

coupling circuit, permitting greater phase shifts in this and other elements than would otherwise be permissible. As indicated above, more gain can be obtained by connecting several such units in tandem. The balanced feedback amplifier, with the feedback leads or the interstage leads crossed over, makes for less stringent requirements on the phase shift in the feedback circuit than obtain in the case of the usual unbalanced, feedback-stabilized amplifier.

Fig. 2 shows a two-stage unbalanced amplifier (single string or single line amplifier) for amplifying waves received from incoming circuit 1 and transmitting the amplified waves to outgoing circuit 2. The first stage comprises a vacuum tube 41, shown by way of example as a screen-grid tube of the heater type. The second stage comprises a vacuum tube 42, shown by way of example as a three-element tube.

The tubes 41 and 42 are connected to output transformer 47 and input transformer 48, respectively, by bridge circuits 45 and 51 which function in the manner indicated above with reference to the bridge circuits 5 and 11. The primary winding of transformer 47 forms one diagonal of bridge circuit 45; and the secondary winding of transformer 48 forms one diagonal of the bridge circuit 51. The four ratio arms of the bridge 45 comprise four resistances R_o , KR_o , KR and R , respectively, the resistance R_o being the plate-cathode resistance in tube 42. The four ratio arms of this bridge circuit comprise resistances r_1 , kr_1 , kr and r , respectively, the grid and cathode of tube 41 being connected across arm r_1 .

The plate of tube 41 is connected to the grid of tube 42 through a stopping condenser as in the case of tubes 3 and 4 of Fig. 1. A feedback path 65 connects the output circuit of the amplifier to the amplifier input circuit, the feedback through this path rendering the amplifier more stable than it would be without feedback and reducing distortion produced by the amplifier. The path 65 comprises two conductors 66 and 67, with a stopping condenser 19 connected in the conductor 66, and with a resistance 68 connected across the conductors 66 and 67. This resistance controls the amount of feedback, and therefore controls the gain of the amplifier as well as the degree of stabilization and the degree of distortion suppression effected by the feedback. To obtain the desired phase for the feedback, the conductor 66 connects the cathode of tube 41 not to the cathode of the tube 42 but to a point on the output circuit of tube 42 which is at an alternating potential different from its cathode potential and of the same sign as its alternating anode potential relative to its cathode potential, and the conductor 67 then connects the cathode of tube 42 not to the cathode of tube 41 but to a point on the input circuit of tube 41 which is at an alternating potential different from its cathode potential and of the same sign as its alternating control grid potential relative to its cathode potential. Thus, the potentials of the cathodes differ, the difference being the voltage across the feedback leads 66 and 67. The cathode of tube 42 is shown grounded.

In this amplifier there is a phenomenon which is conveniently referred to as "local feedback", that is, feedback around a single tube as distinguished from the whole amplifier. The source of this local feedback is in two places. The first and usually most important source is the plate current of the first tube flowing through the

coupling circuit and grid leak to the cathode of the second and thence through the feedback path to the cathode of the first tube. This causes a voltage drop to be produced across the feedback resistances, which is in the grid-cathode circuit of the first tube. The other source is in the second stage. Plate current of this tube flowing around the output bridge circuit divides at the feedback point and part flows around the feedback path through the R_o of the first tube and then through the coupling circuit to cathode thus introducing an IZ drop in the grid-cathode circuit of the second tube. Both of these sources of local feedback are present inherently in this circuit. The circuit can be so designed as to minimize them.

Fig. 3 shows a two-stage, unbalanced amplifier which is a modification of the amplifier of Fig. 2. In Fig. 3 a heater type tube 42' is shown in the second stage, and the cathode of the first stage, instead of the cathode of the second stage, is grounded and connected to the negative pole of the plate battery 25. The local feedback in this amplifier circuit tends to be considerably less than in the amplifier circuit of Fig. 2. In Fig. 3 an inductance coil (retard coil or choke coil) 78 is used in place of the resistance 68 of Fig. 2, to control the amount of the feedback.

The amplifiers of Figs. 2 and 3 can be operated with feedback stabilization at very low frequencies without introducing singing difficulties and with attendant advantages of the stabilizing feedback, including reduction of modulation and reduction of phase shift, as well as constancy of gain with variation of frequency and of battery potentials. These amplifiers are well suited for voice frequency systems in which high stability, low phase shift, low distortion, or a very flat gain-frequency characteristic is desirable. Examples of such applications are amplifiers for transmission measuring sets, program circuit repeaters, transatlantic cable amplifiers, voice frequency carrier telegraph repeaters, and telephoto systems.

Figs. 2 and 3, as well as Fig. 1, eliminate one-stage as compared to a three-stage amplifier. This decreases the number of circuit elements, (only one interstage coupling circuit being required, in addition to the feedback path), so that the stringency of the requirements as to phase shift in the feedback circuit is decreased and control of phase shift around the feedback loop and reduction of singing tendency are facilitated.

The amount of gain reduction effected by the feedback through circuits 15 and 65 of Figs. 1 to 3 may be large, for example, of the order of 30 db. The gain of the amplifier without feedback should then correspondingly exceed the gain required with feedback. For example, the gain without feedback may be of the order of 65 db, and the feedback may reduce the gain to say, a value of the order of 35 db.

While the ratio arms of the bridge circuits described above have been referred to as resistances, these bridge arms may contain reactances, (which usually would be capacitive), to obtain a good balance because of the tube and wiring capacities. In general the bridge arms may be so proportioned as to cause but small loss in both input and output circuits.

What is claimed is:

1. A wave translating system comprising two stages of vacuum tubes and circuits so coupling said tubes in a closed loop as to render operation

of said system more stable than it would be without feedback, said circuits comprising a connection from the plate of one tube to the grid of the other tube, an impedance, means connecting one terminal of said impedance to the plate of said other tube and to the cathode of said one tube, and means connecting another terminal of said impedance to the cathode of said other tube and to the grid of said one tube.

2. A wave amplifying system comprising two stages of vacuum tubes, a network coupling said stages in tandem, and circuits so feeding waves back from the output side of the second stage to the input side of the first stage as to reduce the gain of said system to a value lower than would obtain with no feedback, said circuits comprising a connection from the plate of one tube to the grid of the other tube, an impedance, means connecting one end of said impedance to the plate of said other tube and to the cathode of said one tube, and means connecting the other end of said impedance to the cathode of said other tube and to the grid of said one tube.

3. A wave amplifying system comprising two stages of vacuum tubes, a network coupling said stages in tandem, and circuits so feeding waves back from the output side of the second stage to the input side of the first stage as to reduce the distortion introduced by the system as compared to the distortion that the system would introduce without feedback in the system, said circuits comprising a connection from the plate of one tube to the grid of the other tube, an impedance, means connecting one end of said impedance to the plate of said other tube and to the cathode of said one tube, and means connecting the other end of said impedance to the cathode of said other tube and to the grid of said one tube.

4. A two-stage push-pull amplifier comprising a connection from the plate of one tube in one stage to the grid of a second tube in the other stage, a connection from the plate of a third tube in said one stage to the grid of a fourth tube in said other stage, a connection from a point of the plate circuit of said second tube at an alternating potential different from the cathode to a point on the grid circuit of said third tube at an alternating potential different from the cathode, and a connection from a point on the plate circuit of said fourth tube at an alternating potential different from the cathode to a point on the grid circuit of said first tube at an alternating potential different from the cathode.

5. A vacuum tube circuit comprising means so feeding back waves in said circuit as to reduce distortion produced in said circuit and render operation of said circuit more stable than it would be without feedback, and means for increasing the transmission efficiency of said last mentioned means comprising means feeding back waves which neutralize shunt effects of inherent tube and wiring capacities of the circuit.

6. A push-pull vacuum tube amplifier having means so feeding back waves in the amplifier as to render operation of the amplifier more stable than it would be without feedback, and means adjusting the impedance of a common branch of the amplifier output circuit for second order products to the value for maximum suppression of third order output.

7. A push-pull vacuum tube amplifier having means so feeding back waves in the amplifier as to render operation of the amplifier more stable than it would be without feedback, the external output impedances of the tubes of the last stage

of the amplifier being so low as to render the suppression of third harmonic by feedback of third harmonic substantially independent of feedback of second harmonic.

- 5 8. A push-pull vacuum tube amplifier having means so feeding waves back in the amplifier as to render operation of the amplifier more stable

than it would be without feedback, and means forming a low impedance shunt path for the parallel singing path through the two paths of the push-pull circuit in parallel, and forming a high impedance shunt for the said feedback loop path. 80

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