

Sept. 24, 1935.

S. T. MEYERS

2,015,082

ELECTRIC WAVE TRANSLATING SYSTEM

Original Filed Dec. 31, 1930 4 Sheets-Sheet 1

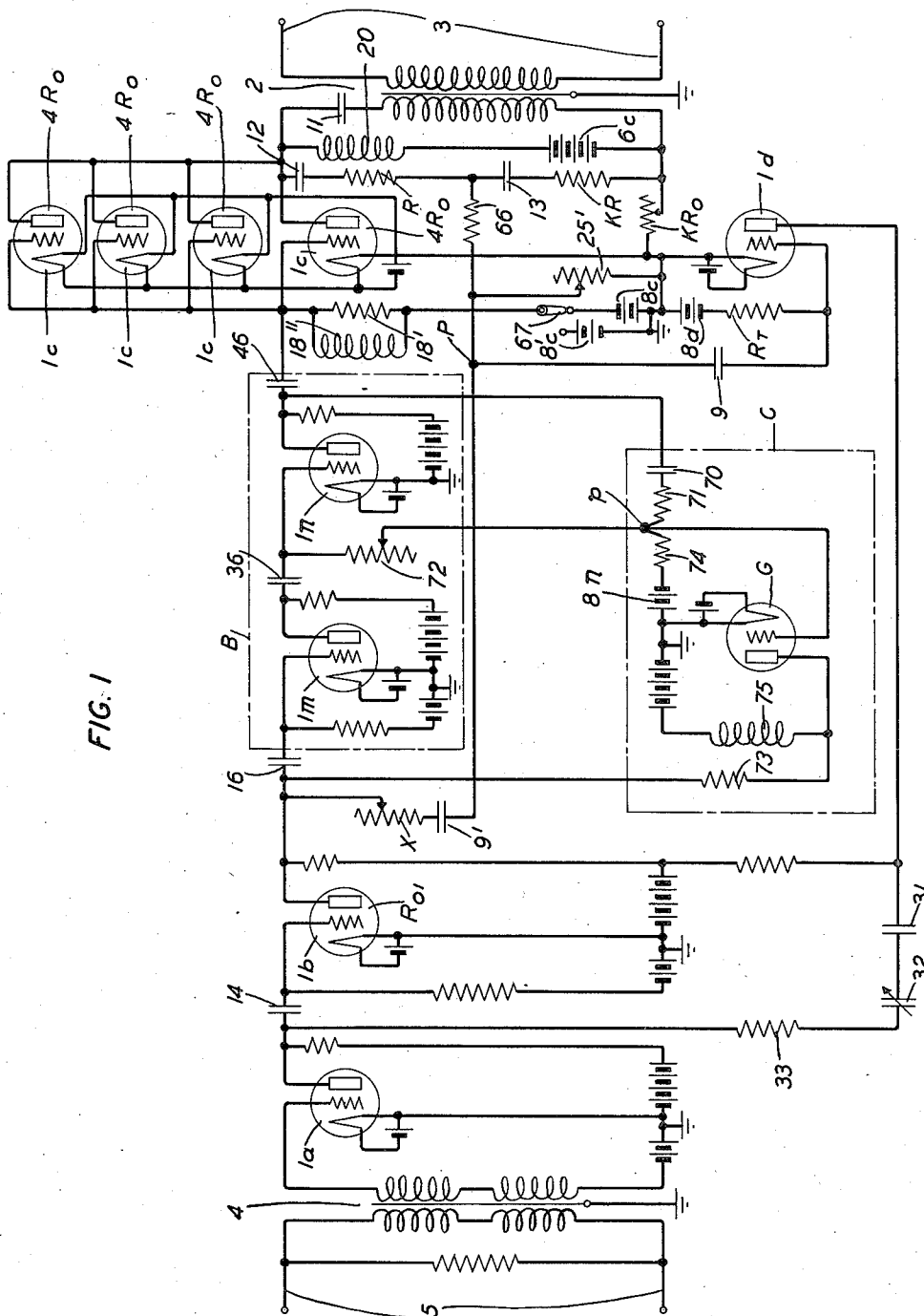


FIG. 1

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ELECTRIC WAVE TRANSLATING SYSTEM

Original Filed Dec. 31, 1930 4 Sheets-Sheet 2

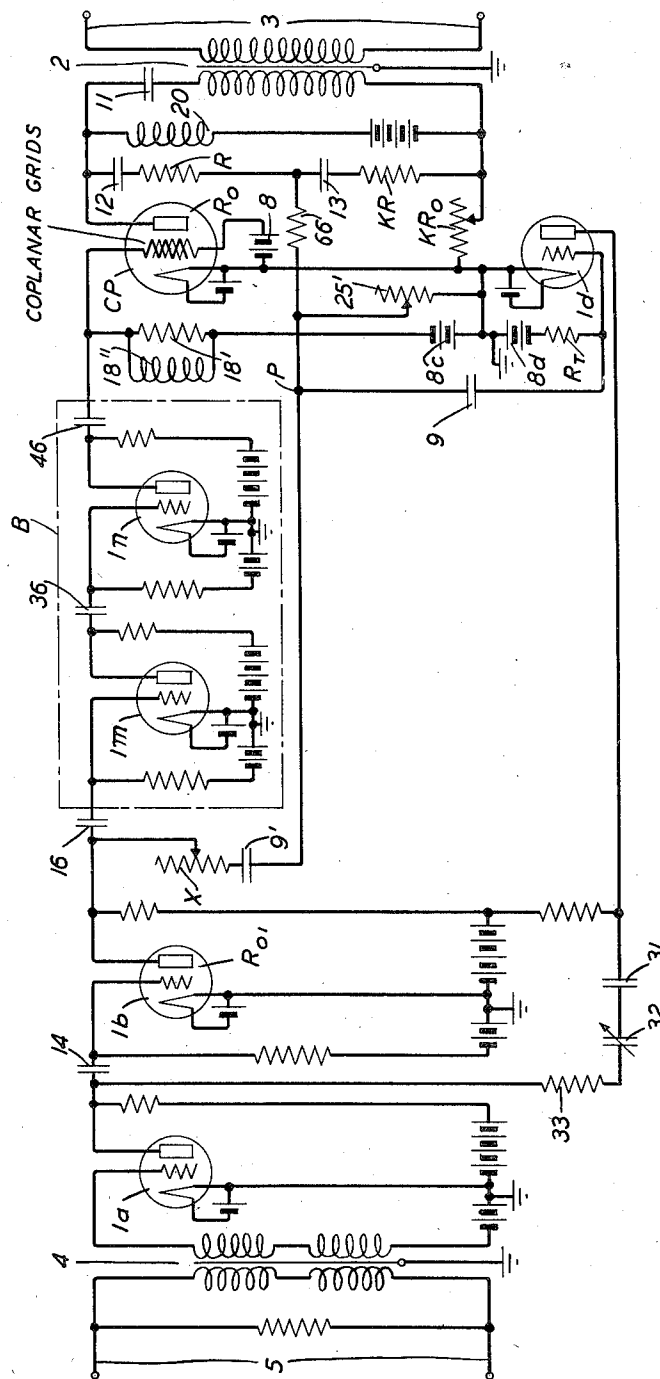


FIG. 2

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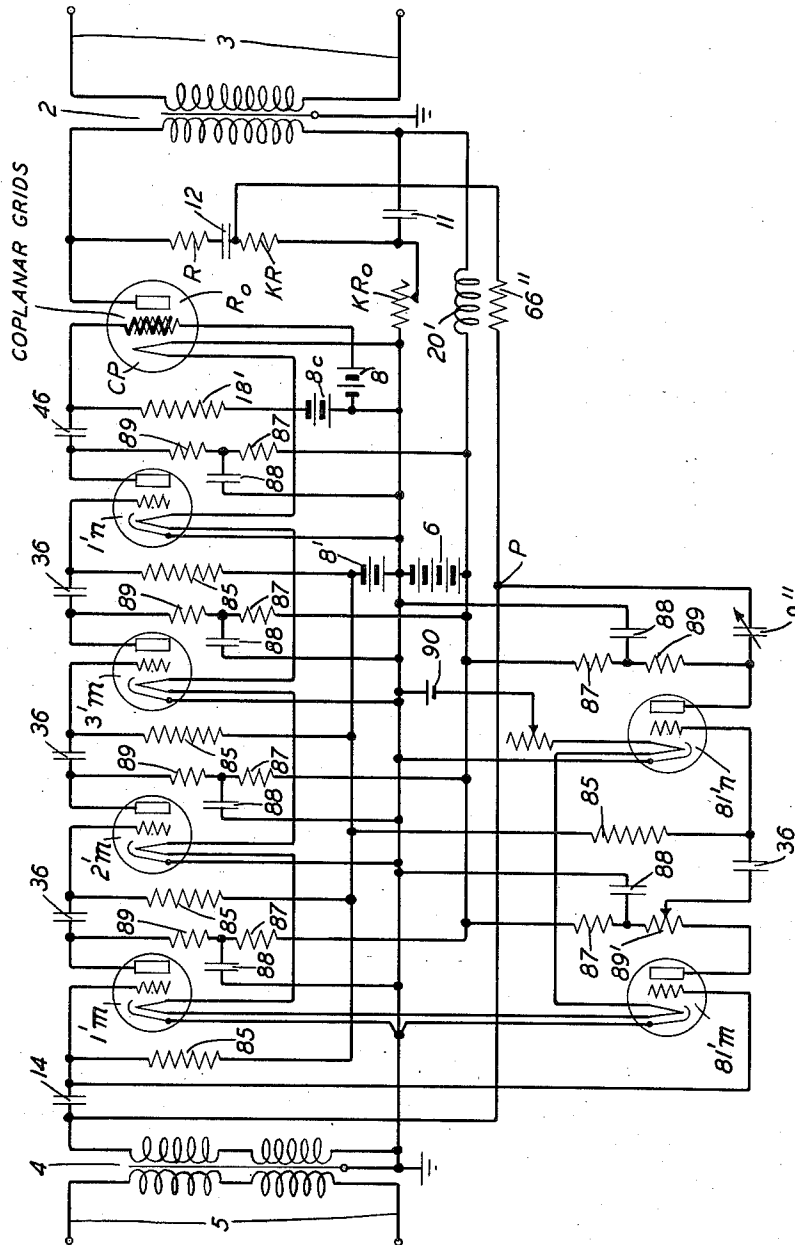
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ELECTRIC WAVE TRANSLATING SYSTEM

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FIG. 4



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2,015,082

ELECTRIC WAVE TRANSLATING SYSTEM

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Application December 31, 1930, Serial No. 505,802

Renewed December 14, 1933

6 Claims. (Cl. 179—171)

This invention relates to wave translating systems, especially such systems involving electric space discharge devices, as for example electric space discharge amplifiers.

5 An object of the invention is to control distortion production in said systems, as for instance to reduce asymmetric distortion and/or other distortion produced in vacuum tube amplifiers.

10 In one specific aspect the invention is a circuit in which distortion components generated in a vacuum tube amplifying device of high load capacity are so fed back in the circuit as to reduce the amount of distortion produced by the device, and in which, without necessitating increase of
15 the plate voltage or decrease of the power output of the device, a decrease is effected in the variation which the device causes the gain of the circuit to undergo with variation of voltage input to the circuit. In one specific embodiment of the
20 invention shown in the drawings, the vacuum tube amplifying device is a coplanar grid vacuum tube with a negative biasing potential on the control grid and a positive biasing potential on the other grid, which is in substantially the same space re-
25 lation as the control grid with respect to the cathode and the anode or plate. Even for moderate plate voltage, with the positive grid the power output of the tube can be high without necessitating driving the control grid positive, and there-
30 fore without necessitating wide variation of the input impedance of the tube. Important advantages of this stability of the input impedance are that it makes for gain stability of the circuit and for stability of the phase shifts in the circuit.
35 This stability of gain and phase shift are especially important in the case of amplifiers of a type to which the invention is applied in the above mentioned embodiment of the invention, in which distortion components generated in the tube are
40 isolated from the fundamental waves by balance and are so fed back in the circuit as to reduce the amount of distortion produced by the vacuum tube device as referred to above; for, as explained hereinafter, the balance desired in order to isolate
45 the distortion components from the fundamental waves is deleteriously affected by variation of the gain and the phase shifts in the circuit.

50 In another specific embodiment of the invention which is shown in the drawings, a special gain corrector circuit is employed which is responsive to gain changes caused by varying input impedance of the vacuum tube device to produce complementary gain changes in an anterior portion of the circuit as explained hereinafter, in
55 order to stabilize the gain. This embodiment may

employ a three electrode tube or the coplanar grid tube or any suitable type of tube as the vacuum tube device.

Another specific embodiment of the invention which is shown in the drawings is a vacuum tube 5 circuit of the type in which distortion components produced by transmission of fundamental waves through an amplifier comprising a vacuum tube device are isolated from the fundamental waves by balance and the isolated distortion components 10 are so fed back in the circuit as to reduce the amount of distortion produced by the device; and in this embodiment the means for isolating the distortion component by balance comprises an auxiliary vacuum tube amplifier for transmitting 15 the fundamental waves substantially without distortion and balancing the waves so transmitted against waves transmitted through the distorting vacuum tube device to neutralize the fundamental component of the opposed distorted waves 20 from said device and thereby yield the distortion components without fundamental waves. As explained hereinafter, the use of the auxiliary vacuum tube amplifier tends to prevent objectionable regeneration in the circuit and facilitates obtain- 25 ing correct phase relations for causing the balance to obtain over a considerable frequency range and for considerable variation of transmission level.

Other objects and features of the invention will 30 be apparent from the following description and claims.

Fig. 1 is a circuit diagram of an amplifier circuit embodying a form of the invention including the gain corrector circuit referred to above; 35

Fig. 2 shows an amplifier circuit embodying a form of the invention which employs a coplanar grid tube as referred to above;

Fig. 3 shows an amplifier system embodying a form of the invention which employs an auxiliary 40 balancing vacuum tube amplifier as referred to above; and

Fig. 4 shows a modified form of the system of Fig. 3.

Fig. 1 shows an amplifier circuit of a general 45 type disclosed in British Patent 317,005 and in U. S. patent to H. S. Black, No. 2,003,282, June 4, 1935. In such circuits one portion, which in amplifying waves gives them an odd number of phase reversals, has the distortion components 50 that are generated in that portion neutralized, and that portion will therefore be referred to as the compensated portion. To effect this neutralization, the distortion components generated in the compensated portion of the amplifier are 55

fed in proper amplitude from the output side of that portion to its input side so that after amplification by that portion they will reappear at its output side in such phase as to neutralize themselves and thus be suppressed.

The odd number of phase reversals in the compensated portion of the amplifier can be effected, for example, by having an odd number of amplifying stages in that portion, since the driving voltage generated in a vacuum tube is in phase opposition to the grid voltage which produces it. An amplifier circuit of this general type is shown in Fig. 5 of the above mentioned British Patent 317,005, and of the above mentioned U. S. Patent 2,003,232. However, in that figure the compensated portion of the amplifier includes but one amplifier stage. Fig. 1 of the present application shows a similar amplifier which however, has two additional stages (or a total of three stages) in the compensated portion. The two additional stages are shown in Block B. The reference characters common to the Fig. 5 and the Fig. 1 which are mentioned just above designate the same elements in the two figures. The block B consisting of the two additional stages has been inserted between the condenser 16 and the grid leak resistor 18' of tubes 1c, so that the compensated portion of the amplifier contains not only the tubes 1c but also tubes 1m and 1n of the two amplifying stages included in block B.

In Fig. 1, an input transformer 4 impresses waves from circuit 5 upon the grid of tube 1a. These waves may be, for example, voice waves to be amplified, or voice modulated carrier waves to be amplified and transmitted over carrier wave wire transmission systems or to radio transmitting antennae or waves received over such systems. The waves impressed on the grid of tube 1a are amplified by tubes 1a, 1b, 1m, 1n, and 1c in cascade connection, the tubes 1c being connected in parallel to each other. The amplified waves from tubes 1c are impressed on the outgoing circuit 3 through a Wheatstone bridge circuit which has the space path resistance R_0 of tubes 1c as one ratio arm of the bridge and has the primary winding of output transformer 2 in the output diagonal of the bridge. Each of the tubes 1c has its space path resistance $4R_0$. The four ratio arms of the bridge are designated by their resistance values $4R_0$, KR_0 , KR and R , K being a constant. The driving voltage generated in the space paths of tubes 1c may be considered as a generator, in series with resistance R_0 . The usual plate, filament and grid batteries for the tubes are shown. The usual grid battery for tubes 1c is 8c; that for the tube 1d is 8d; and that for tube 1n is 8n. The battery 8c supplies negative biasing potential to the grids of tubes 1c through grid leak resistor 18' and choke coil 18'' in parallel. The steady plate current for tubes 1c passes from the plate battery 6c for those tubes through a choke coil 20, the space discharge paths in the tubes and the resistance KR_0 . Condensers 11, 12, 13, 14, 16, 36 and 46, and also condensers 9 and 9', are blocking or stopping condensers, of negligibly low reactance for the waves to be amplified.

Across the resistance KR and KR_0 in series, is a circuit forming one diagonal of the bridge and comprising a resistance 66 in series with three parallel paths. One of these paths is the blocking condenser 9', a resistance x (shown adjustable) and the space path resistance R_{01} of tube 1b. Another, which is of negligibly low admittance at the frequencies of the waves to be

amplified, extends through the stopping condenser 9, input or coupling or grid leak resistor R_r for a vacuum tube 1d and grid biasing battery 8d for that tube, in series. The third parallel path is an adjustable resistance 25'. This diagonal will be referred to as the input diagonal of the bridge or the feed back diagonal; for the driving voltage generated in the space path of tube 1b appears in this diagonal and is opposed therein by the driving voltage generated in the space paths (of tubes 1c) located in the ratio arm R_0 of the bridge, and moreover the voltage across R_r which results from this opposition of the two driving voltages is amplified by tube 1d which feeds the amplified voltage back to the grid of tube 1b through a path comprising condensers 31 and 32, resistance 33 and condenser 14. However, the value of resistances x and 66 are so adjusted that this opposition of the driving voltages gives a zero value of resultant voltage across R_r as regards the signal wave, or in other words makes point P a null point as regards the signal wave. Consequently, only the distortion components produced in the compensated portion of the amplifier and appearing in the driving voltage generated in tubes 1c are fed back to the grid of tube 1b. In other words, the tendency for tubes 1c to feed fundamental or signal waves back to the grid of tube 1b through resistance 66 and tube 1d is neutralized by the tendency of tube 1b to feed back to its own grid through x and tube 1d, so that only distortion components (for example modulation products) arising in the compensated portion of the amplifier and appearing in the driving voltage generated in tubes 1c are fed back to the grid of tube 1b. These distortion components undergo an odd number of phase reversals in the five tubes 1d, 1b, 1m, 1n and 1c, so that they reappear in reversed phase in the driving voltage in the space path of each of the tubes 1c, and the magnitude of resistance 25' so adjusts the amplitude of the reappearing waves that they balance out or neutralize their originating distortion waves in the driving voltage in the space paths of tubes 1c. Thus distortion in the compensated portion of the amplifier is eliminated.

However, the degree to which such neutralization or elimination is realized in the amplifier depends on the accuracy with which the circuit elements are adjusted in such a way that any distortion component fed back from the plate-filament space path of the last stage 1c through tubes 1d, 1b, 1m, 1n and 1c, returns to the plate filament space paths of tubes 1c with its original amplitude but with its phase shifted 180 degrees. That is, in order that the distortion voltage shall balance out, the product of the voltage amplifications and diminutions around the circuit should be unity, and the phase shift should be 180 degrees. Since the effectiveness of the circuit thus depends on the production of two voltage waves of equal amplitude and opposite sign, a good balance requires that the phase difference be very close to 180 degrees and that the gain of the circuit change very little after the balance is attained. Consequently, it is desirable to provide accurate compensation for undesirable phase shifts in the amplifier caused, for example, by interstage coupling circuits, and moreover to provide such phase compensation without unduly changing the shape of the gain-frequency characteristic of the amplifier. For example, to compensate for such phase shifts under normal conditions, condensers 31 and 32 can be used (the

capacity of condenser 32 preferably being variable and large relative to that of condenser 31, to facilitate close or fine adjustment of the phase), or any suitable type of phase compensating means desired can be used, as for instance the type disclosed in Nyquist Patent 1,894,322, January 17, 1933.

The resistance KR_0 is adjustable, to provide for correcting unbalance of the Wheatstone bridge arising from variations in plate impedance of tube 1c caused for example by variations in the power supply voltages for the tube or by substitution of one tube for another. To make the distortion components balance out in the space path of tube 1c as explained above, the magnitude of the regenerated distortion components appearing across the feed-back diagonal of the bridge can be controlled by adjusting the variable resistances 25' in that diagonal, and the condenser 32 can be adjusted to give the desired phase correction. If desired, a harmonic analyzer (not shown) can be connected across circuit 3 in order to tell when the best adjustment for 25' and 32 has been effected.

Since the load or work circuit for the amplifier is comprised in a diagonal of the balanced Wheatstone bridge which is conjugate to the feed-back diagonal, the impedance of the amplifier as seen from the load or work circuit is the same as it would be without feed back and is independent of the impedance of the feed-back diagonal, and the feed-back voltage is independent of the impedance of the work circuit. The system reduces both odd and even order distortion components at the same time, and can stabilize gain and afford high load capacity.

The system increases the load carrying capacity of electric space discharge tubes (1) not only by attaining an increase in load capacity of very great importance by suppression of distortion components of frequencies other than the fundamental frequencies and thereby permitting the tubes to operate over a larger range of their grid-voltage plate-current characteristics but also (2) by attaining a second increase of very great importance in the load capacity by regeneration of fundamental waves in such a way as to control gain in a desired manner, as for example, to prevent undesired lowering of gain, for the fundamental waves.

In connection with this latter increase, it should be noted that the system provides means for correcting for distortion caused by improper degree of amplification of fundamental waves, as for example caused by amplification of a fundamental wave of a given frequency different amounts for different input amplitudes, or as for example caused by amplification of two waves of respectively different fundamental frequencies, different amounts, respectively. For example, if a wave of a given fundamental frequency is amplified in the compensated portion of the amplifier (i. e., in any or all of tubes 1m, 1n and 1c or the circuits associated with the tube or tubes) to a degree less than, say, the normal amplification for that portion of the amplifier, then for that frequency the voltage which tubes 1c feed to the resistance R_T or cause to appear across the resistance R_T tends to be lower than normal, i. e., less than the fundamental which is applied across R_T from tube 1b through R_0 and x . As a result, the tendency toward lower than normal gain of the system for the fundamental wave of the given frequency is checked. Similarly, if the given frequency is amplified to a degree greater, instead of less, than

normal in the compensated portion of the amplifier, then for that frequency the voltage across R_T from tubes 1c tends to be higher than the voltage of that frequency which is applied across the resistance R_T by tube 1b through R_0 and x ; and as a result the tendency toward higher than normal gain of the system for the fundamental wave of the given frequency is checked. The system compensates for too low or too high gain for fundamental waves, at the same time that it suppresses components of frequencies other than fundamental frequencies.

Since the isolated distortion components, (obtained across the resistance R_T) are amplified separately from the signal in an amplifier shown as comprising a single tube 1d (through which the signal components do not pass), and are then fed back to the grid of tube 1b, the amplification of the isolated distortion components can be controlled independently of the amplification of the signal components, and can, for example, be made greater than the amplification of the signal components.

A summary of the main features and of the operation of the circuit of Fig. 1 as so far described will now be given. In the output circuit of the last stage is a balanced Wheatstone's bridge, the plate resistance of the tubes of this stage forming one of the arms. The output transformer connects to two points of the balanced bridge conjugate to the feed-back diagonal. The bridge voltage across the points connecting to the feed-back diagonal, and also that across resistance 25, is exactly proportional to and in phase with the so-called "driving voltage" in the plate circuit of the last stage. In order to produce a null point at the junction of resistances 63 and 25' in this diagonal, a second voltage source is introduced in this diagonal, so that a second voltage is applied to resistance 66, but from an earlier portion of the circuit and in series with a resistance x . The proper phase relationship may be readily obtained for example, by going back an odd number of stages. If the circuit to which x connects is far enough back (i. e., if x is far enough back), then the voltage applied to the null point in series with x will be free from distortion, and across the null point we will have present only what is not wanted in the load or work circuit. The amplifier is a feed-back amplifier possessing the property that a voltage applied to its input or to the left of x appears in its output but does not appear at the null point. Accordingly, in feeding back distortion waves, i. e. waves that are not wanted ultimately, such waves are introduced to the left of x in order that they will not reappear across the null point and cause the process to be repeated. In the circuit shown, the distortion voltages across the null point are applied to the left of x through the aid of an auxiliary or pick-up tube 1d. This means of application is shown merely by way of example, the fundamental requirement being that the feed-back path from the output bridge to x include an even number of tubes or some unilateral or other suitable circuit arrangement not introducing phase shift. Under these conditions the feed-back may be so adjusted that it produces in the output coil two currents that are exactly out-of-phase and equal in amplitude to the distortion currents produced by the compensated portion of the amplifier, namely, that portion having the resistance x at its input side and having the bridge at its output

side. The amplifier is thus a balanced type of feed-back amplifier.

In obtaining curves or measurements of harmonic production, the magnitude of the feed-back may be adjusted separately and individually for harmonics of different orders, for example second harmonics and third harmonics. The same balance does not necessarily hold for both second harmonics and third harmonics. This is attributed to the presence of harmonics in the stages preceding x . While these harmonics do not appear across the null point they do appear in the output transformer of the amplifier. The second harmonics in these stages make it necessary to feed back less from the null point than would otherwise be required for a balance, whereas the production of third harmonics in these stages sometimes requires more feed-back than would otherwise be required in order to get complete suppression of third harmonics with tubes of a given type, for example, Western Electric Company type 104-D or "O" tubes, in the output stage. This relationship is not universally true for this type of tube but is random, it being possible to have third harmonics produced by this type of tube reversed 180° from the position just described. In such a case, for complete suppression of third harmonics there would be required, not over compensation in the compensated portion of the amplifier, but, as for the case of complete suppression of second harmonics, under compensation in that portion, inasmuch as the second and third harmonics from the preceding portion would tend to counteract the second and third harmonics, respectively, generated in the compensated portion. In general, harmonic production in the uncompensated portions of the circuit should be maintained small in order to facilitate great suppression. This harmonic production can be maintained small, and the suppression consequently can be very much improved by employing a plurality of stages in the compensated portion of the amplifier to reduce the load (grid swing) on the stages preceding x . Distortion in the preceding stages ahead of x then does not become troublesome until after much greater suppressions have been attained. The spread between the best balance for second and third harmonics is greatly reduced.

The increase in the number of stages in the compensated portion of the amplifier considerably improves the overall gain regulation of the amplifier, also. To explain this simply, it is convenient to interpret the change in gain as the result of superimposing an extra voltage analogous to a modulation, and hence, which can be suppressed like modulation, but at the same time is the same frequency as the fundamental itself. In other words, as indicated above, an excess or shortage of fundamental is self-compensated for in a way exactly similar to the way in which the various modulation products themselves are suppressed. Assuming that the change in gain of the amplifier before regeneration occurs only in the portion of the amplifier to the right of R_x , gain stabilization with regeneration will be equivalent to the amount of harmonic suppression.

The system of Fig. 1 as so far described differs from the Fig. 4 of the Black application, Serial No. 298,155, and likewise from the Black application, Serial No. 455,239, by including resistance 66. When this resistance is omitted (i. e. short circuited), then, as pointed out in each of those

applications, the condition for balancing out the fundamental to isolate the distortion components originating in the compensated portion of the amplifier is

$$x = \frac{R + R_0}{\text{gain of compensated portion of amplifier}}$$

With the resistance 66 in circuit, the corresponding condition is

$$x = \frac{(R + R_0) + R_{66} \left(\frac{1 + K}{K} \right)}{\text{gain of compensated portion of amplifier}}$$

wherein R_{66} is the value of the resistance 66. Increasing the gain or number of stages in the compensated portion of the amplifier tends to reduce x and therefore increases (deleterious) plate circuit modulation in the stage preceding the compensated portion; but this tendency is counteracted by increasing R or resistance 66. While it is desirable to have R large within limits, the use of resistance 66 (of sufficient magnitude) avoids any necessity for making R inconveniently or undesirably large in order to obtain a suitably large value of x . By varying the resistance the magnitude of the distortion components fed back through tube 1d can be varied to obtain the desired balance or distortion suppression without changing the null point, i. e. without disturbing the desired condition that the fundamental voltage on the grid of tube 1d is (normally) zero.

With the circuit of Fig. 1 as so far described, as the load (current or power output, or grid swing) is increased to the value at which the grids in the output stage are driven positive, there is a sudden drop in the suppression of the distortion or cross-talk currents. This may be attributed to two causes. One is the change in phase-shift with the stabilizing action of the circuit. Analysis of the circuit shows that there are three round trip paths or loops around which regeneration may take place. Each one of these paths has phase-shift. One path or loop, in particular, which is in the corrected or compensated portion of the amplifier changes when the grids of the output stage are positive. The opposing regeneration in this path tends to decrease. When this path changes the other two change simultaneously. Therefore, all three paths changing cause an aggregate change in phase shift which is sufficient to destroy the good balance obtained before the grids went positive. The second reason for the sudden decrease in suppression is the change in amplitude. This inherently tends to accompany a change in phase, but aside from this, even if the reactive phase shift in the circuit be zero, the amplitude will change for still another reason. Regeneration in the corrected or compensated portion of the amplifier destroys the balance or null point if it is varied or changed. Hence, even if the phase be entirely corrected, because of amplitude balance it will also still be necessary to eliminate this change in regeneration entirely or else make it sufficiently small.

A separate gain corrector, shown in block C in Fig. 1, may be used to compensate for or eliminate the gain change caused by the change in grid impedance of the last stage when the grids of that stage go positive. It comprises a vacuum tube amplifier G fed from tube 1n through stopping condenser 70 and resistor 71, and fed from tube 1m through stopping condenser 36 and variable resistance 72, and feeding back to the grid of tube 1m through resistance 73 and stopping condenser 16. The grid battery 8n for tube 1n is shown as

serving also as the grid battery for tube G. This battery 8*n* supplies grid biasing potential for tube G through a resistance 74, and supplies grid biasing potential for tube 1*n* through resistances 74 and 72 in series. Plate current for tube G is supplied through choke coil 75.

Regeneration around the path through tubes 1*m* and G would tend to increase the gain of tube 1*m*, (since the number of tubes or phase reversals around the path is even); whereas regeneration around the path through tubes 1*m*, 1*n* and G would tend to decrease the gain of tubes 1*m* and 1*n* (since the number of tubes or phase reversals around the path is odd). However, resistance 72 is so adjusted, for example, that the voltages applied to the grid of tube G from tubes 1*n* and 1*m*, which are 180° different in phase, are equal in magnitude and therefore cause the grid of tube G, i. e. the point *p*, to be a null point or point of zero A. C. potential when the grid impedance of tubes 1*c* is normal. Under these conditions the tube G feeds nothing back to tube 1*m*. However, when the grids of tubes 1*c* are driven positive by the signal, and the grid impedance of tubes 1*c* therefore decreases, departing from its normal value, then a decrease in the output voltage of tube 1*n* tends to result but the tendency is checked because the voltage decrease causes the voltage applied to the grid of tube G from tube 1*m* to overpower the voltage applied to the grid of tube G from tube 1*n* and thereby, provided the value of resistance 74 bears the proper relation to the value of resistance 72, result in such feed-back action or regeneration around the path through tubes 1*m* and G as to increase the gain of tube 1*m* sufficiently to substantially counteract or neutralize the gain decrease of tube 1*n* and thereby stabilize the overall gain of tubes 1*m*, 1*n* and 1*c*.

The ratio of 74 to 72 is governed by how much the amplification from the plate of tube 1*m* through G and back to the plate of 1*m*, (which varies with different circuit designs) must be reduced to make it equal to unity. In other words, 74 is similar to 25' in function. The value of 72 is determined in the same manner in which *x* is determined. The values of 72, 71 and 74 should be such as not to place too low impedance across the plate circuit of tube 1*m* or tube 1*n*.

Summarizing the operation of the gain corrector C, the adjustment of resistance 72 is such that when the grid impedance of tubes 1*c* is normal the grid of tube G, i. e. the point *P*, is a null point. Feed-back action which occurs in the path through tubes 1*m* and G, the path through tubes 1*m*, 1*n* and G, and the path through tube 1*n* and resistances 71 and 72, is such feed-back operation as will change to stabilize the overall gain of tubes 1*m*, 1*n* and 1*c* when the grid impedance of tubes 1*c* changes.

By switch 67, grid battery 8'*c* can be connected in circuit in place of the battery 8*c*, so that tubes 1*c* will be given, instead of the negative grid bias, a positive grid bias sufficient to maintain the grid potential of these tubes always positive and cause them to operate on a straighter portion of their static characteristics of input voltage versus output current. Such operation with positive instead of negative grid bias results in less variation of gain caused by changing grid impedance; because the average impedance is nearly constant due to some secondary emission in the grid circuit which tends to prevent the grid current versus grid voltage curve from ris-

ing to its normal value. The impedance at any point is given by the reciprocal of the slope of this curve. For such operation with positive instead of negative grid bias, variation of plate impedance with load, i. e. with grid swing, is also less, because the operating point is on a steeper portion of the static characteristic. Further, in such operation with positive instead of negative grid bias, for a given power output the space current is less. Moreover, at least in some cases, harmonic production in the tubes of the last stage is less than for negative grid bias. This is an added advantage in that the requirements on the suppressor are reduced.

When the grid potential of the last stage is maintained always positive the tube or tubes used in that stage preferably have high filament emission so that there is at all times an abundant supply of electrons. Such a tube has a long straight characteristic in the region of positive grid potentials before the saturation point is reached. An example of such a tube is the Western Electric Company type 102-D or "V" tube. A special tube construction which has been used for operation with the grid always positive is a Western Electric Company type 205-D or "E" tube with the grid of the "V" tube. This makes a tube with a high amplification factor and with which a large space current at a low plate voltage can be obtained which varies substantially linearly with input voltage over a large range of positive grid potentials.

When the grid voltage of a vacuum tube sweeps over a portion of the tube characteristic including both the negative and positive regions of grid potential the input impedance changes between a very high impedance and a low impedance. Therefore, since the range of negative grid potentials for which plate current will flow is a relative small range, this change in the input impedance will occur if the grid is operated with a negative bias, when a large grid swing is employed. This change in impedance will introduce distortion. This change in impedance and this distortion are avoided by maintaining the grid always positive. Maintaining the grid always positive avoids also the limitation on grid swing that arises in the case of negative grid bias because of the fact that a vacuum tube characteristic has considerable curvature as the region of zero current is approached, and the consequent fact that when negative grid bias is used distortion will occur unless the input voltage range is confined to considerably less than the total range of negative grid potentials for which plate current will flow (with any given plate potential employed). When a tube is operated with the grid always at positive potential, the input impedance is not high as for negative grid potentials, but is a comparatively low resistance and therefore the circuit of the tube becomes in effect a power operated system as distinguished from a voltage operated system.

Fig. 2 shows a circuit like that of Fig. 1 except that the gain corrector C is omitted and the last stage employs, instead of four single-grid tubes, an electric space discharge tube CP having coplanar grids, such for example as the coplanar grid tube disclosed by H. A. Pidgeon and J. O. McNally in Patent 1,923,686, August 22, 1933 or in the Proceedings of the Institute of Radio Engineers, volume 18, pages 266 to 293, February, 1930. The use of the coplanar grid tube avoids the variation of grid or input impedance of the last stage which caused the gain 75

change for which the gain corrector C of Fig. 1 was designed to compensate, and has other important advantages. The coplanar grid tube has two grids, each active elementary area on either grid being close to a corresponding active elementary area on the other grid and being at substantially the same location as that corresponding area with respect to the cathode and the anode or plate. By way of example, each grid may have its lateral wires lie in the same plane or cylindrical surface as the lateral wires of the other grid and alternate with them. One of the grids is made positive by battery 8. The other is the control grid, to which the signal is applied, and which is given a negative biasing potential by battery 8c.

The grids function alike as far as their action upon the plate circuit is concerned, and at the same time are independent and function independently of one another. Therefore, one can be maintained positive and the other negative, so that the same operating point can be reached as would be used for a three element tube with its grid positive, while at the same time there is available a negative grid which can be used for driving, i. e. as a control grid. The use of the coplanar grid tube not only avoids the variation of grid or input impedance of the last stage of the amplifier circuit, but moreover affords a high value of that impedance, in the interest of low power losses in the circuit. It also avoids occurrence of any objectionable local oscillations or other deleterious effects that tend to result from secondary electron emission or negative resistance consequent to positive potentials on control grids.

If desired, as for example when the grid swing for the last stage may be so large as to drive the control grid positive even in the case of the coplanar grid tube, the gain corrector C of Fig. 1 can also be employed in Fig. 2. In other words, a coplanar grid tube or coplanar grid tubes can be employed in the last stage of Fig. 1 as one is employed in the last stage of Fig. 2.

The system in Fig. 3 is an amplifier which is a modification of that shown in Fig. 2, especially in that Fig. 3 employs an amplifier auxiliary to the signal amplifier for producing the null point P. Fig. 3 omits the tube 1b of Fig. 2 and includes in the compensated portion of the system not only the tubes 1m, 1n and CP of Fig. 2, but also tubes 2m, 3m and 4m in cascade connection with each other between the tubes 1m and 1n. The auxiliary amplifier comprises tubes 81m, 82m, 83m, 84m and 81n, all in cascade connection.

The null point P, or point normally at zero fundamental potential, is produced in general as in Fig. 2, by feeding to the grid leak resistance Rr of the tube 1d, (i. e., to the grid of the tube 1d or the point P), two signal or fundamental waves of equal amplitude but opposite phase, one from the bridge in the output circuit of tube CP and the other from the plate of tube 1a (or the grid of tube 1m, i. e. the input to the compensated portion of the amplifier or system). The path for feeding the fundamental wave to point P from the output bridge is through variable resistance 66', corresponding to resistance 66 of Fig. 2. Also, the path for feeding the fundamental wave of equal amplitude but opposite phase to point P from the plate of tube 1a includes a resistance x' corresponding to the resistance x of Fig. 2; but it further includes the auxiliary amplifier, interposed between the resistance x' and the point P so as to amplify the

potential delivered by resistance x' before applying that potential to point P.

As in the system of Fig. 2, only modulation components or distortion components produced in the compensated portion of the amplifier or system appear at point P and these components are fed back or returned to the plate of tube CP through a path comprising tube 1d and the compensated portion of the amplifier or system. In Fig. 3 this path includes a variable phase correcting condenser 32' and a variable attenuating or amplitude adjusting resistance 33' connecting the plate of tube 1d to the grid of tube 1m, as the plate of tube 1d in Fig. 2 is connected to the grid of tube 1m through the phase correcting condensers 31 and 32 and the resistance 33. The distortion components return to the plate of tube CP with the same amplitude that they originally had at that point, but with their phase reversed, so that they balance themselves out or neutralize themselves at that point and consequently do not appear in the load or work circuit.

In Fig. 3, as in Fig. 2, there should be an odd number of phase reversals, (obtained, for example, by an odd number of amplifying stages) in the regenerative path from the plate of the last stage (of the compensated portion of the amplifier) through the feed-back path to the grid of the first stage of the compensated portion of the amplifier and through the compensated portion back to the plate of the last stage.

It has been pointed out above that when a null point P is produced by the system of Fig. 2 there are three regenerative paths, one being the loop in the compensated portion of the amplifier, and that regeneration in this loop resulting from production of the null point in this manner is detrimental. In the circuit of Fig. 3 the (unilateral) auxiliary amplifier used in producing the null point P eliminates this regeneration in this loop and facilitates maintaining the null point over a wide band of frequencies. Considerable feed-back has been used in such an amplifier without occurrence of singing. The load on the auxiliary amplifier was very light (note the large number of stages or considerable gain in the compensated portion of the system before the last stage) so that the auxiliary amplifier did not itself introduce appreciable harmonics. The circuit using the auxiliary amplifier for production of the null point showed an improved stability, and less sudden increase of harmonic production as a function of power output. The uncorrected distortion voltages were made very small, and the adjustments made for maximum suppression of second harmonics served for third harmonics also. The phase shift of the auxiliary or null point amplifier and the compensated portion of the system approached one another and the phase correcting condenser 32' was common to both. When gain stabilization did take place the change in phase shift was not as great as for the case of null point production without use of the auxiliary amplifier. These factors were of assistance in eliminating sudden decrease of distortion suppression with load increase.

The coplanar tube CP has its control grid maintained at negative potential by grid battery 8c, through choke coil 18''. This tube has its other grid maintained at positive potential by grid battery 8. Tubes 2m, 3m, 4m, 1n, 82m, 83m, 84m and 81n have grid leak resistors 85, connected to grid batteries 8' or 8n. The grid leak resistance for tube 1m includes the resistance

x' in series with the grid circuit resistor 85' of tube 81*m*. A plate battery 6 supplies space current for tube 1*n* (which may be, for example, a Western Electric Company type 101-D or "L" tube), through a frequency selective circuit comprising an inductance 86 and a capacity 88 in addition to a plate inductance 90 for the tube. Plate batteries 6 supply space current for all of the tubes except 1*n* and CP through resistance-capacity filters which are individual to the tubes and each of which comprises a resistor 87 and a condenser 88 in addition to a plate resistor 89 for its tube. These tubes may well be Western Electric type 239-A tubes, for example. With this type of tube the plate current is small and therefore the resistance 89 through which it is supplied can be ordinary lavite resistances directly connected to the plates without lead wires, in order that the interstage grid-to-filament capacity may be small. If desired, any suitable phase correcting or compensating means may be employed, as for example the above mentioned phase compensating means of the Nyquist Patent 1,894,322. In any case it is of assistance to have the total capacity shunted across the input of each stage small, and to that end it is helpful to have the capacity to ground of each of the individual elements of the interstage coupling circuits a minimum. Therefore, it is advantageous to have the physical dimensions of these elements small, as for example, to have the tubes and sockets and the coupling condensers of small dimensions and to have the grid and plate wiring eliminated as far as feasible.

If desired, as for example to ease the requirements on the filters for the plate current supply to the tubes, the capacity of one or more of the interstage coupling condensers 36 in Fig. 3 or in any of the figures of the drawings can be made sufficiently small to assist in maintaining the amplifier gains at low frequencies below the singing point, instead of being given the large capacity usually given condensers which are to function merely as blocking or interstage coupling condensers. The small capacity can counteract singing tendency at frequencies below the utilized frequency band, and yet need not be so small as to cause objectionable phase shift within or above that band. When such a condenser of small capacity is used it is preferably one in the compensated portion of the amplifier, as compensation is then afforded for its phase shift.

The system of Fig. 4 is an amplifier which is a modification of the amplifier of Fig. 3, and which is more simple. Fig. 4 omits the tubes 1*a*, 4*m*, 82*m*, 83*m*, 84*m*, and 1*d* of Fig. 3, and has tubes 1'*m*, 2'*m*, 3'*m*, 1'*n*, CP, 81'*m* and 81'*n* which correspond respectively to tubes 1*m*, 2*m*, 3*m*, 1*n*, CP, 81*m* and 81*n* of Fig. 3 but are all shown as heater type tubes (for example Western Electric Company type 247-A tubes) except the coplanar tube CP. The filament current for indirectly heating the cathode elements is supplied from a voltage source shown as a filament heating battery 90. Battery 6 supplies space current for tube CP through a choke coil 20' and the primary winding of transformer 2 in series. The grid of the first stage of the auxiliary amplifier is fed from the grid of the first stage of the compensated portion of the system directly, instead of through a resistance such as x' of Fig. 3. That is, the resistance x' is omitted. A grid leak resistor 85 forms the entire grid leak resistance for tube 1'*m*, whereas the grid leak resistance for tube 1*m* of Fig. 3 comprises the resistance x'

in series with a resistor 85'. The null point P is fed from the output bridge through a resistance 66'' corresponding to the resistance 66' of Fig. 3; but the connection through which the null point P feeds distortion components to the grid of the first stage of the compensated portion of the amplifier omits the phase correcting condenser 32' and attenuating resistance 33' of Fig. 3. However, phase correction can be obtained by a variable condenser 9''. In Fig. 4 the plate resistor for the first stage of the auxiliary amplifier, instead of being a simple resistance such as 89 in Fig. 3, is a potentiometer 89' for varying the gain of the auxiliary amplifier. The potentiometer is so adjusted as to give amplitude balance between part of the signal or fundamental output of the compensated portion of the system fed to point P through resistance 66'' and part of the input amplified by the auxiliary amplifier, and consequently the signal or fundamental potential at point P should be zero when the phase shift through the main amplifier or compensated portion of the system is an odd multiple of 180° and the phase shift through the auxiliary amplifier is an even multiple of 180°. The distortion voltage then appearing at point P is fed back through the main amplifier or compensated portion of the system so that it balances itself out or neutralizes itself at the plate of the last stage and leaves the output to the load or work circuit free from distortion. The operation of the system is similar to the operation of the system of Fig. 3, and will be apparent from the explanation above of the operation in Fig. 3, without further description.

For the sake of simplicity the invention has been explained above with reference especially to pure resistance impedances where impedances have been described as external or ratio arms of the Wheatstone bridge. However, the invention is not limited to the case in which the bridge, if used, has its ratio arms resistances. They, as well as the load, may be impedances of any character, (proper provision being made, of course, for the necessary supply of steady potential to the plates and grids of the tubes). Where R_0 has been treated as constituting one arm of the bridge, the plate-filament capacity is so small that its reactance at frequencies of the order of those of the waves to be amplified is so great compared to the impedance R_0 as to be negligible.

What is claimed is:

1. A circuit comprising a vacuum tube device, means for transmitting to said device fundamental waves which produce distortion components in said device, a vacuum tube amplifier for transmitting the fundamental waves substantially without distortion and opposing the waves so transmitted against waves transmitted through said device, said amplifier having such transmission efficiency and phase shift that the fundamental waves transmitted therethrough neutralize the fundamental component of the opposed distorted waves from said device and thereby yield the distortion components without fundamental waves, and means for causing these isolated distortion components to reduce the amplitude of distortion components delivered by said circuit.

2. A circuit comprising a vacuum tube device, means for transmitting to said device fundamental waves which produce distortion components in said device, a unilateral wave transmission path for transmitting the fundamental waves substantially without distortion and op-

posing the waves so transmitted against waves transmitted through said device, said path having such transmission efficiency and phase shift that the fundamental waves transmitted there-
5 through neutralize the fundamental component of the opposed distorted waves from said device and thereby yield the distortion components without fundamental waves, and means for causing these isolated distortion components to be
10 so regenerated in said circuit as to reduce the amplitude of distortion components delivered by said circuit.

3. A circuit comprising a vacuum tube device, means for transmitting to said device funda-
15 mental waves which produce distortion components in said device, a unilateral wave transmission path for transmitting the fundamental waves substantially without distortion and opposing the waves so transmitted against waves
20 transmitted through said device, said path having such transmission efficiency and phase shift that the fundamental waves transmitted there- through neutralize the fundamental component of the opposed distorted waves from said device
25 and thereby yield the distortion components without fundamental waves, and means for causing these isolated distortion components to be so regenerated in said circuit as to control the amplitude of distortion components delivered by
30 said circuit.

4. A wave translating system comprising a source of fundamental waves, a wave path associated therewith and containing means amplifying said waves and increasing their energy and
35 distorting them, a unilateral wave transmission path associated with said source for transmitting the fundamental waves substantially without distortion and opposing the waves so transmitted against waves transmitted through said means,
40 said unilateral path having such transmission efficiency and phase shift that the fundamental waves transmitted therethrough neutralize the

fundamental component of the opposed distorted waves from said means and thereby yield the distortion components without fundamental waves, and means so feeding back these isolated distortion components to said first means that their
5 amplification therein reduces the distortion produced by said first means.

5. A wave translating system comprising a source of fundamental waves, a wave path associated therewith and containing means amplifying
10 said waves and increasing their energy and distorting them, a unilateral wave transmission path associated with said source for transmitting the fundamental waves substantially without distortion and opposing the waves so transmitted
15 against waves transmitted through said means, said unilateral path having such transmission efficiency and phase shift that the fundamental waves transmitted therethrough neutralize the fundamental component of the opposed distort-
20 ed waves from said means and thereby yield the distortion components without fundamental waves, and means so feeding back these isolated distortion components to said source that their amplification in said first means reduces the dis-
25 tortion produced by said first means.

6. A wave translating circuit comprising an electric space discharge device having an anode, a cathode and two grids therebetween, said grids being located principally in the same surface with
30 respect to said anode and said cathode, means for supplying a steady negative bias potential to one of said grids, means for supplying a steady positive bias potential to the other of said grids, means supplying to said wave translating cir-
35 cuit signals causing potential swing of said one grid that generates distortion in said device, and means so feeding back said distortion from the output of said device to its input as to reduce said distortion.

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