

Dec. 21, 1937.

H. S. BLACK

2,102,670

WAVE TRANSLATION SYSTEM

Original Filed Aug. 8, 1928

6 Sheets-Sheet 1

FIG. 1

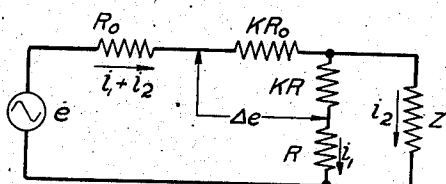


FIG. 2

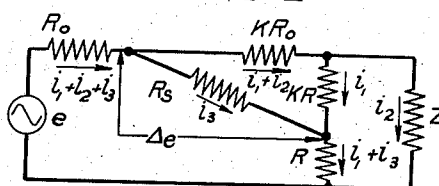


FIG. 3

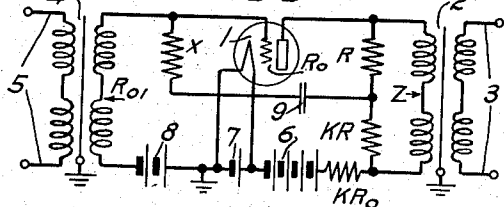


FIG. 3A

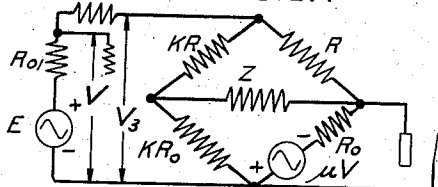


FIG. 3B

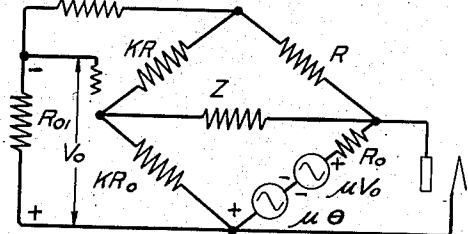


FIG. 3C

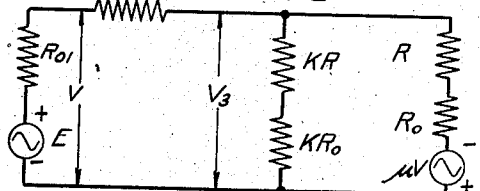


FIG. 3D

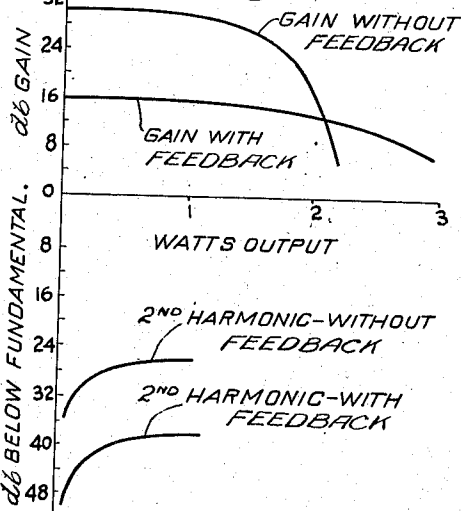
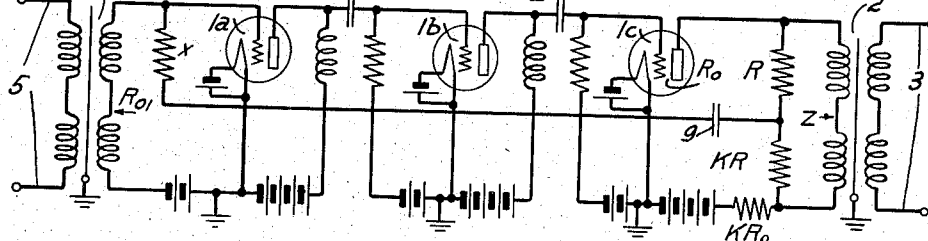


FIG. 3E



INVENTOR.

HAROLD S. BLACK

BY

H. A. Burgess

ATTORNEY

Dec. 21, 1937.

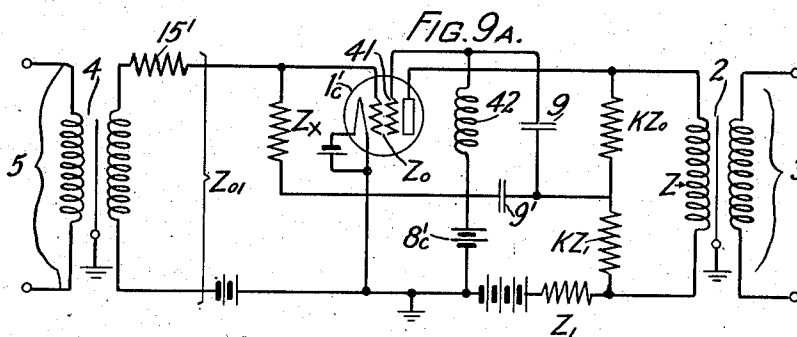
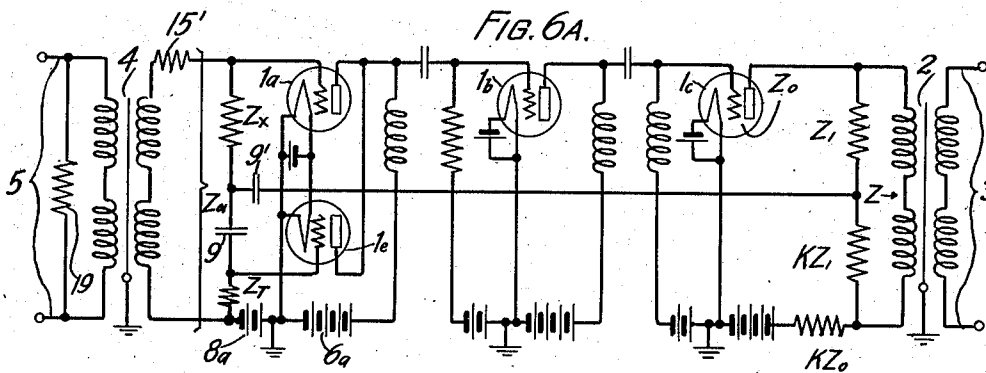
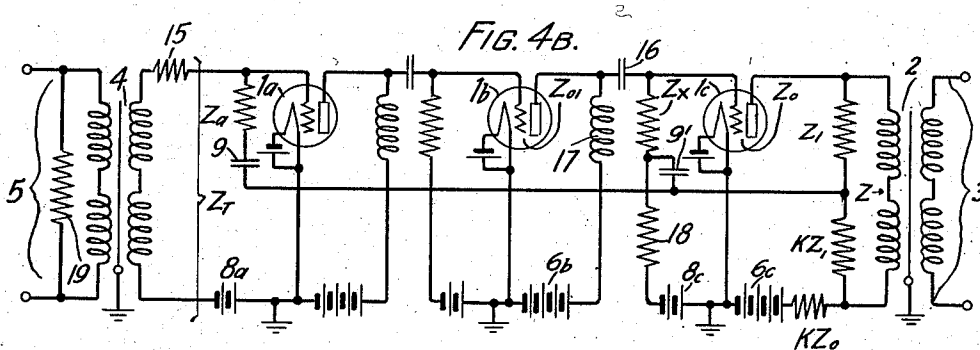
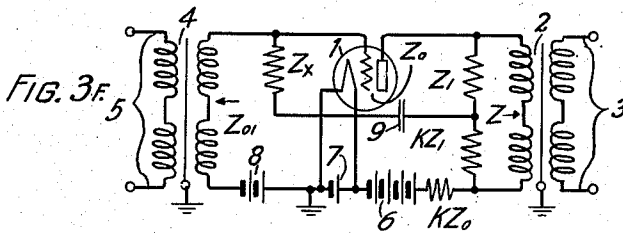
H. S. BLACK

2,102,670

WAVE TRANSLATION SYSTEM

Original Filed Aug. 8, 1923

6 Sheets-Sheet 2



INVENTOR
H. S. BLACK

BY

H. A. Burgess

ATTORNEY

Dec. 21, 1937.

H. S. BLACK

2,102,670

WAVE TRANSLATION SYSTEM

Original Filed Aug. 8, 1923

6 Sheets-Sheet 3

FIG. 4

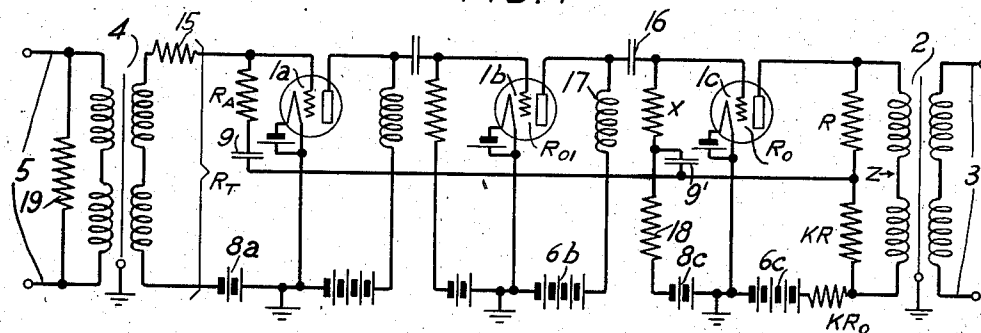


FIG. 4A

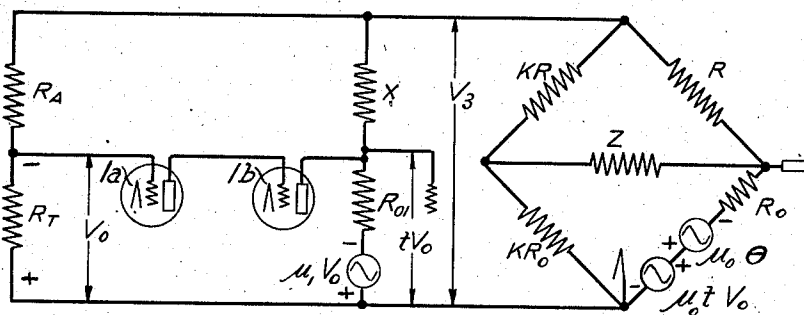
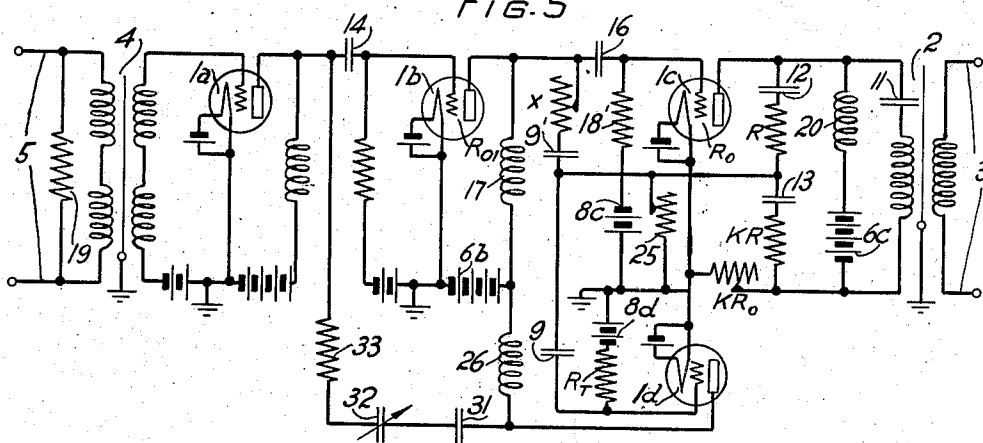


FIG. 5



INVENTOR
HAROLD S. BLACK
BY *H. A. Burgess*
ATTORNEY

Dec. 21, 1937.

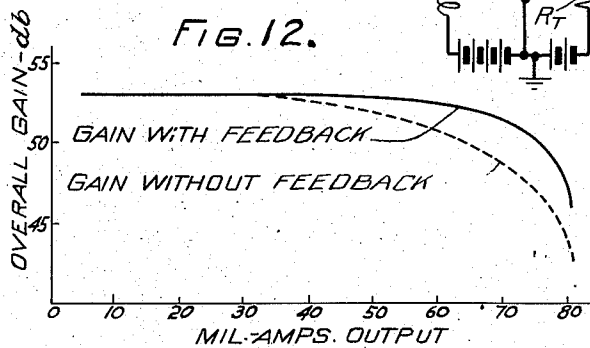
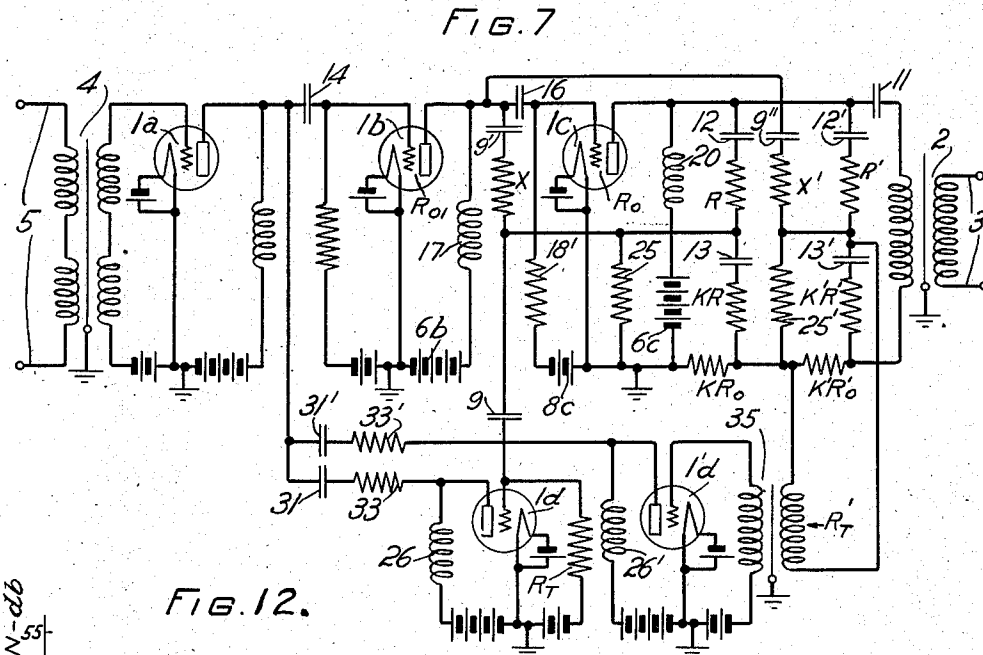
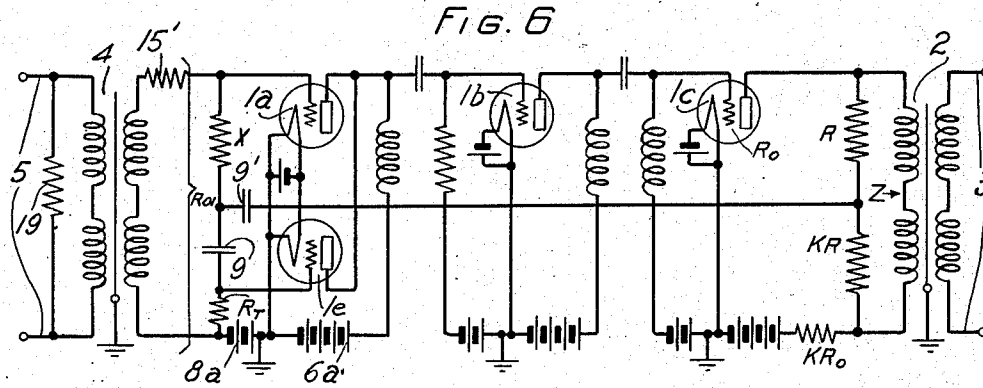
H. S. BLACK

2,102,670

WAVE TRANSLATION SYSTEM

Original Filed Aug. 8, 1923

6 Sheets-Sheet 4



INVENTOR
HAROLD S. BLACK
BY *H. A. Burgess*
ATTORNEY

Dec. 21, 1937.

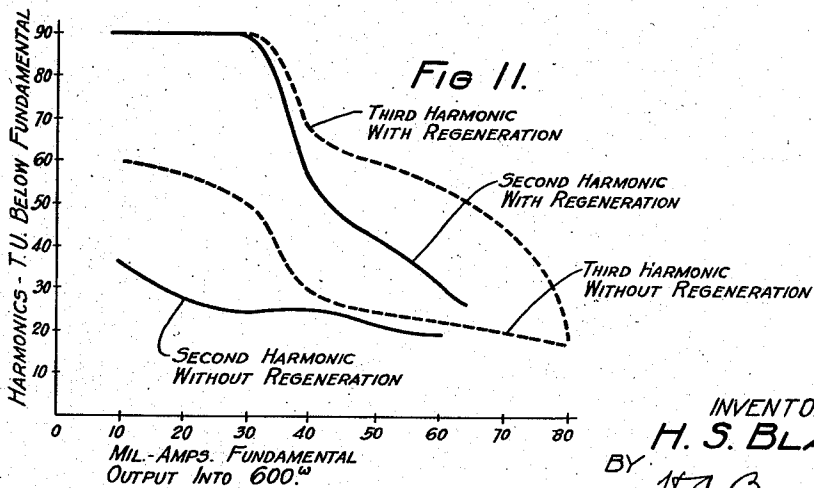
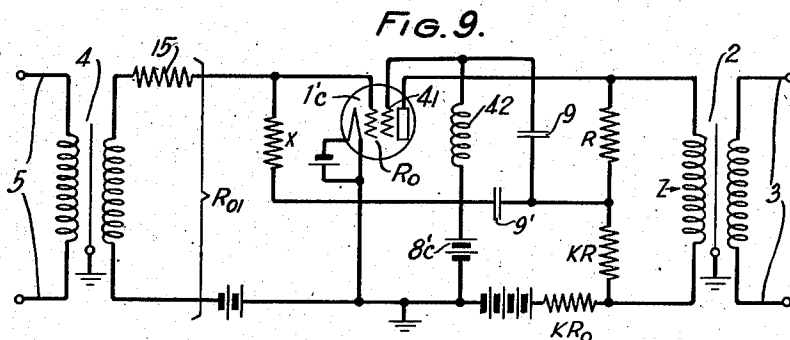
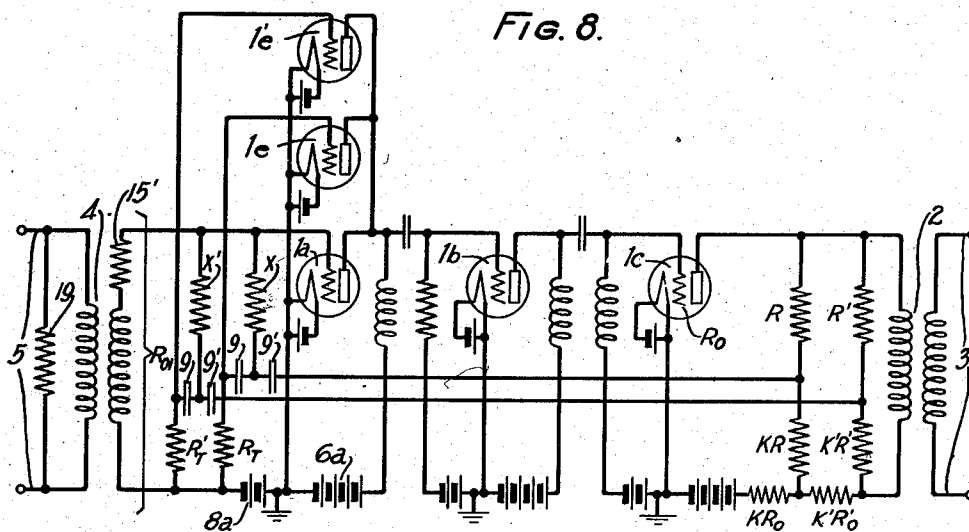
H. S. BLACK

2,102,670

WAVE TRANSLATION SYSTEM

Original Filed Aug. 8, 1923

6 Sheets-Sheet 5



INVENTOR
H. S. BLACK
BY *H. A. Burgess*
ATTORNEY

Dec. 21, 1937.

H. S. BLACK

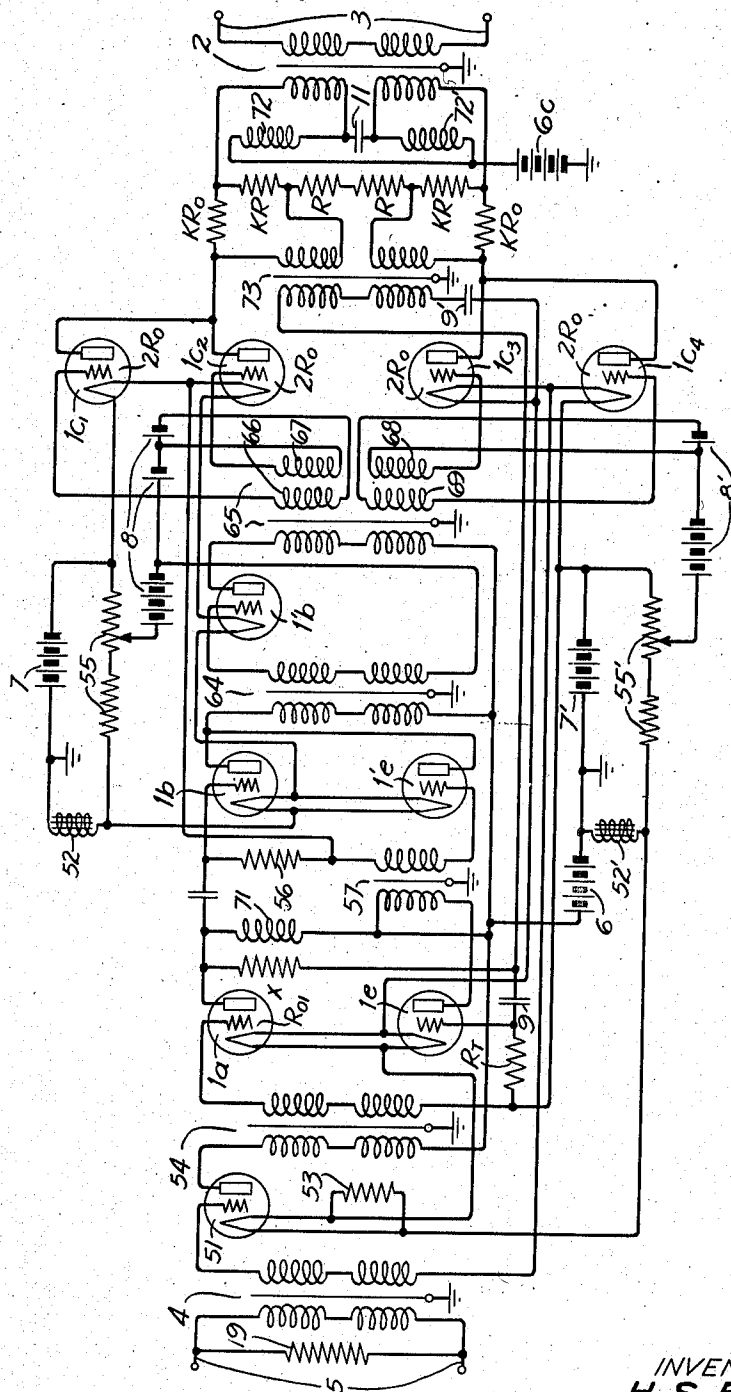
2,102,670

WAVE TRANSLATION SYSTEM

Original Filed Aug. 8, 1923

6 Sheets-Sheet 6

FIG 10



UNITED STATES PATENT OFFICE

2,102,670

WAVE TRANSLATION SYSTEM

Harold S. Black, New York, N. Y., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Original application August 8, 1928, Serial No.
298,155. Divided and this application Decem-
ber 3, 1929, Serial No. 411,223. Renewed Oc-
tober 21, 1932. In Canada May 21, 1929

52 Claims. (Cl. 178-44)

This is a division of my prior application Serial No. 298,155, filed August 8, 1928 for Wave translation systems.

This invention relates to wave translation systems, as for example systems for amplifying electrical variations with the aid of electric space discharge devices.

It is common experience that increase of the power output of vacuum tubes or electric space discharge devices tends to increase distortion of signalling or other waves transmitted by the devices, and tends to lower the gain of the circuits of the devices.

At high values of output power, gain may become so low that further increase of input amplitude or decrease of output impedance produces no further increase of power output.

However, in many applications of vacuum tubes, long before the power output of the tube reaches the maximum value that the tube is capable of delivering or seriously lowers the gain of the tube circuit, distortion becomes so great as to render further increase of output power inadvisable. Representative instances in the field of application of amplifiers, for example, are voice frequency telephone repeaters, carrier frequency amplifiers common to a plurality of signaling channels in carrier wave multiplex signaling systems, amplifiers for public address systems, amplifiers for reproducing music from records, power amplifiers used as transmitting or sending amplifiers in radio or wire transmission systems, amplifiers for operating loud speaking receivers for radio sets or the like, and sending amplifiers for high quality broadcasting transmitters.

In each such instance, the higher the quality of transmission required, or in other words, the less the distortion permissible, the sooner is the maximum permissible output power reached, that is, the lower is the ratio of maximum permissible output power to the maximum output power that the tube or tubes of the amplifier stage is capable of delivering. Therefore, the higher the transmission quality demanded, the more inefficiently has the power capacity of the tube or tubes been used, and consequently when both high transmission quality and high output of power are required in systems of the types commonly employed, the power capacity of the tubes has to be especially great because only a small fraction

of the total power that each tube is capable of delivering can be utilized. The present tendency in practice is toward higher and higher transmission quality, and also the number of applications and installations requiring high output power is rapidly increasing, and moreover, the tendency is toward higher quality even where enormous power is demanded and interference or disturbances tending to introduce noise in the waves transmitted is great, as in transatlantic radio telephony.

In general, the design limitations for vacuum tubes of the types commonly employed are such that the highest output power capacity of the tube is obtained only at a sacrifice of maximum gain obtainable, or of operating efficiency, or of both.

In the case of a carrier frequency amplifier common to a plurality of signaling channels in a carrier wave multiplex signaling system, the tendency of the amplifier to modulate a wave of one frequency by a wave of another frequency, increases greatly with increase in the output power, and there results therefore a very large increase in crosstalk and interference between the various channels, this increase being more serious the larger the number of channels.

Therefore, a major problem in devising vacuum tube systems, as for example vacuum tube amplifier systems, is the securing of high output of power without attendant disadvantages, as for example without increase of first cost or decrease of operating efficiency of the systems, and especially in the case of vacuum tube amplifiers and repeaters, without sacrifice of quality of signal reproduction.

Representative objects of the invention are (1) economically to increase the load carrying capacity of wave translation systems, as for example, systems for amplifying electrical variations with the aid of electric space discharge devices, (2) to control modulation in such systems, (3) to amplify waves without modulation or other distortion, (4) to facilitate the handling of large loads by electric space discharge devices, and (5) to stabilize the functioning of systems comprising electric space discharge tubes, as for example to prevent variations of tubes or power from affecting gain.

In one specific aspect the invention is a signal

wave amplifying system of a type claimed in my copending application Serial No. 606,371, filed April 22, 1932, for wave translation systems. In systems of such type, fundamental or applied components and distortion components produced in an amplifying device, as for example a vacuum tube amplifier circuit, are so fed back as to reduce the magnitude of the distortion components of both odd and even orders in the output circuit of the device for a given power output of fundamental and stabilize the gain and increase the load carrying capacity of the system.

In the above mentioned specific aspect of the present invention, in obtaining reduction of distortion, increase of gain stability and high load capacity in a system comprising an amplifying device, undesired reduction in the gain of the system is avoided by isolating the distortion components from the fundamental components and feeding back only the distortion components when the gain of the device has no tendency to depart from a normal or prescribed value, and, when such tendency exists, so controlling feedback of fundamental components as to cause reduction or prevention of departure of the gain of the system from its normal or prescribed value. Other objects and aspects of the invention will be apparent from the following description and claims.

Figs. 1 and 2 of the drawings are circuit diagrams for facilitating explanation of the invention; Fig. 3 shows a feed-back amplifier embodying one form of the invention; Figs. 3A, 3B and 3C are diagrams, and Fig. 3D a set of curves for facilitating explanation of the operation of the amplifier of Fig. 3; Fig. 3E shows a modification of the amplifier of Fig. 3; Fig. 4 shows a feed-back amplifier embodying another form of the invention; Fig. 4A is a simplified circuit diagram of the amplifier of Fig. 4, for facilitating explanation of the operation of that amplifier; Fig. 5 shows a modified form of the amplifier of Fig. 4; Fig. 6 shows a feed-back amplifier embodying another form of the invention; Fig. 7 shows a modified form of the amplifier of Fig. 5; Fig. 8 shows a similarly modified form of the amplifier of Fig. 6; Fig. 9 shows another modified form of the amplifier of Fig. 6; Fig. 10 shows a carrier frequency amplifier embodying principles of the invention; Figs. 11 and 12 show curves for facilitating explanation of the action of a system of the type of that shown in Fig. 5; and Figs. 3F, 4B and 6A show the circuits of Figs. 3, 4 and 6 respectively with certain of the impedances generalized; and Fig. 9A is a modification of Fig. 9.

The driving voltage in the plate circuit of an amplifier is 180° out of phase with the grid voltage which produces it. For a feed-back amplifier, it is desirable that there be available a voltage which is directly proportional to, and in phase with, the driving voltage in the plate circuit, and which is independent of the impedance of the work circuit. It will be seen from Fig. 1 and the derivation below, that the voltage Δe , which is the drop across resistances KR and KR_0 , fulfills these three conditions.

In the figure, R_0 is a resistance (for example, the resistance of the space discharge path between the plate and the filament of a three electrode vacuum tube); e represents, as a generator, a source of voltage e (for example, the driving voltage e produced in the discharge path by the grid voltage); and Z is an impedance (for example, the impedance of the load circuit or work circuit of the tube). Two resistances designated

by their values R and KR , respectively, are connected in series across the impedance Z , K being a constant. A resistance designated by its magnitude KR_0 is connected between R_0 and the junction of KR with Z . The voltage e causes currents i_1 , i_2 and i_1+i_2 to flow as indicated by the arrows.

The derivation mentioned above is as follows:

$$e = (i_1 + i_2) R_0 (1 + K) + i_1 R (1 + K)$$

$$\Delta e = (i_1 + i_2) R_0 K + i_1 K R$$

$$e = [1 + K] [(i_1 + i_2) R_0 + i_1 R]$$

$$\Delta e = [K] [(i_1 + i_2) R_0 + i_1 R]$$

$$\frac{\Delta e}{e} = \frac{1 + K}{K}$$

The circuit of Fig. 2 is like that of Fig. 1, except that a resistance R_0 is bridged across KR_0 and KR . The current components flowing in the various parts of the circuit of Fig. 2 are indicated by the arrows and their accompanying letters i with the appropriate subscripts. However, in Fig. 2 the currents indicated by i_1 , i_2 and i_1+i_2 and the voltage indicated by Δe are not in general of the same magnitudes as in Fig. 1. When a resistance R_0 is connected across KR_0 and KR , the voltage Δe still fulfills the three conditions mentioned above. Referring to Fig. 2 this is demonstrated as follows:

$$e = (i_1 + i_2 + i_3) R_0 + (i_1 + i_2) K R_0 + i_1 K R + (i_1 + i_2) R$$

$$e = (i_1 + i_2) R_0 (1 + K) + i_1 (1 + K) R + i_3 R_0 + i_3 R$$

$$e = [1 + K] [(i_1 + i_2) R_0 + i_1 R] + i_3 (R_0 + R)$$

$$\Delta e = [K] [(i_1 + i_2) R_0 + i_1 R] = i_3 R_0$$

$$\frac{\Delta e}{e} = \frac{1 + K}{K} \frac{R_0 + R}{R_0}$$

Fig. 3 shows one way in which this voltage may be utilized. In this figure a three-electrode, electric space discharge amplifying device 1 has an anode-cathode space-discharge path of resistance R_0 , which is associated with resistances KR_0 , KR , and R , and impedance Z , in the manner of resistance R in Figs. 1 and 2. The plate-filament resistance R_0 is the reciprocal of the slope of the static characteristic of plate current versus plate voltage of the discharge device at the so called operating point, as explained in the following articles by John R. Carson in the Proceedings of the Institute of Radio Engineers: "Theory of Three Element Vacuum Tube", vol. 7, pp. 187-200, April 1919; "The Equivalent Circuit of the Vacuum Tube Modulator", vol. 9, pp. 243-249, June 1921. (That is,

$$\frac{1}{R_0} = \frac{\partial i_p}{\partial e_p},$$

where i_p and e_p are instantaneous plate current and voltage, respectively.) In Fig. 3 the impedance Z is the primary-to-secondary impedance of output transformer 2 which, together with circuit 3 connected to the secondary winding of the transformer, forms the load or work circuit for the device 1. An input transformer 4 impresses waves from circuit 5 upon the grid of the device 1. These waves may be, for example, voice waves, or voice modulated carrier waves for transmission over carrier wave wire transmission systems or to radio transmitting antennae or waves received over such systems. The usual plate, filament, and grid batteries are shown at 6, 7 and 8. A circuit corresponding to the resistance R_0 of Fig. 2 and comprising the secondary winding or secondary-to-primary impedance R_{01} of transformer 4, a resistance r and a blocking condenser 9 in series is connected across the resistance KR_0 and KR . The grid is

connected to the junction of x and R_{01} . The condenser is a blocking condenser of large capacity, for preventing batteries 6 and 7 from applying steady voltage to the grid. The circuit through which battery 6 supplies plate current for the tube comprises resistance KR_0 in series with two parallel paths, one extending through the primary winding of transformer 2 and the other through resistances KR and R in series.

A characteristic of this circuit of Fig. 3 is that the gain is reduced by the feed-back action. To demonstrate this, it is simpler to redraw the circuit to the form of Fig. 3A. From this it will be seen that R and KR , R_0 and KR_0 form the ratio arms of a balanced Wheatstone bridge, Z takes the place of the galvanometer and E represents a source of voltage E which is applied through a resistance of $(x+R_{01})$ that forms the input diagonal or feed-back diagonal of the bridge. For the condition of balance, it is evident that there is no current in Z due to E , the driving voltage in the grid circuit.

There is some voltage V , from grid to filament. Due to V , there will be a driving voltage μV in the plate circuit, with relative polarity as shown by the plus and minus signs. The presence of this voltage is indicated in Fig. 3A by generator μV .

To investigate the effect of the two generators or voltages E and μV acting simultaneously, use is made of the principle of superposition. This principle is that the current which flows at any point in a circuit, or the difference of potential which is established between any two points in a circuit, due to the simultaneous action of a group of E. M. F.'s located at the same or various points in a circuit, is the algebraic sum of the component currents at the first point, or the component differences of potential between the latter two points, which would be established by the individual E. M. F.'s acting alone.

Due to E alone, there will be a voltage from grid to filament, V_1 equal to

$$V_1 = \frac{x + \frac{K}{1+K}(R_0 + R)}{R_{01} + x + \frac{K}{1+K}(R_0 + R)} E$$

Due to μV acting alone, there will be a voltage from grid to filament V_2 equal to

$$V_2 = -\frac{\frac{R_{01}}{R_{01} + x}}{\frac{1+K}{K} + \frac{R_0 + R}{x + R_{01}}} \mu V$$

or, if

$$\beta_1 = \frac{1}{\frac{1+K}{K} + \frac{R_0 + R}{x + R_{01}}} \left[\frac{R_{01}}{R_{01} + x} \right]$$

$$V_2 = -\mu \beta_1 V$$

These specific values for V_1 , V_2 and β_1 follow directly from the configuration of the specific circuit shown, but, though special to that particular configuration, are given in order to present a concrete illustration of the significance of V_1 , V_2 and β_1 .

By the principle of superposition,

$$V = V_1 + V_2$$

$$V = V_1 - \mu \beta_1 V$$

$$V = \left(\frac{1}{1 + \mu \beta_1} \right) V_1$$

That is, the voltage in the grid circuit (and hence the current in the output impedance Z) is reduced from what it would be if there were no feedback action, and the impedance relations were the same, by a factor

$$\frac{1}{1 + \mu \beta_1}$$

It will now be shown that any distortion (as for example modulation product) produced in the tube is also reduced by the same factor.

Consider the circuit of Fig. 3B. Let any primary distortion voltage produced in the tube be represented as a driving voltage $\mu \theta$, in the plate circuit. Let the voltage drop between the grid and the filament, resulting from the distortion produced in the tube be V_0 . This sets up another driving voltage in the plate circuit, μV_0 , with polarity as shown. As before,

$$V_0 = \beta_1 (\mu \theta - \mu V_0)$$

$$\mu V_0 = \mu \beta_1 (\mu \theta - \mu V_0)$$

$$\mu V_0 = \frac{\mu \beta_1}{1 + \mu \beta_1} \mu \theta$$

$$\mu \theta - \mu V_0 = \frac{\mu \theta}{1 + \mu \beta_1}$$

That is, the final, or resultant, driving distortion voltage in the plate circuit is reduced by a factor

$$\frac{1}{1 + \mu \beta_1}$$

from what it would be without feedback action.

It will be noted that due to the configuration of the elements of the circuit, if a generator is assumed in series with Z , no current will flow in the branch $x+R_{01}$. Hence the impedance of the amplifier as seen from the load or work circuit Z is the same as it would be without regeneration, and is independent of the shunt resistance $x+R_{01}$.

Now to return to a consideration of the gain of the circuit, by the feed-back action the gain is stabilized with respect to variations of tubes and power. If due to any cause, the μ of the tube is reduced, which would reduce the gain, the effective voltage on the grid is increased. Similarly, variations in R_0 are stabilized. The curves of Fig. 3D, which are plotted from observed data, show that by the feedback action the load carrying capacity of the amplifier is substantially increased, the variation of gain with load is reduced, and the ratio of the power output of second harmonic to the power output of fundamental is improved or decreased about 12 decibels. The curves for operation without feedback are for operation with the right hand side of condenser 9 disconnected from the junction of R and KR and connected instead to ground through an impedance (not shown) equal to the impedance with which the feed-back diagonal of the Wheatstone bridge in Fig. 3 is faced by the remainder of the bridge (i. e., equal to the combined resistance of two paths in parallel, one through KR and KR_0 in series and the other through R and R_0 in series). The resistance $(x+R_{01})$ of the feed-back diagonal is so high that substituting an equal resistance across the path through KR and KR_0 would not affect the operation of the circuit. Thus, the curves for operation without feedback are for operation with the external grid-to-filament impedance and the external plate-to-filament impedance for the tube the same as in operation with feedback.

The circuit of Fig. 3 can be modified to comprise a plurality of tubes connected in cascade, in which case μ represents the total amplification from a voltage across the grid of the first tube to a driving voltage in the plate of the last tube. For example, Fig. 3E shows one such modified circuit, with tandem connected tubes 1a, 1b, and 1c replacing the tube 1 of Fig. 3. If the number of tubes be even instead of odd, then an odd number of phase reversals in addition to those produced by the tubes themselves should be produced, as for example by the introduction of an interstage or other transformer with its windings poled to reverse the phase of waves passing through the transformer.

In Fig. 3A consider voltage V_3 . Its value is being contributed to by both E and μV , and these voltages tend to oppose each other. It is possible, therefore, by suitable adjustment of the circuit elements, notably x , to make $V_3=0$. The value of x to accomplish this may be found as follows:

$$\begin{aligned} \text{In Fig. 3C, } V &= (\text{Voltage drop across } x) + V_3 \\ \therefore V &= (\text{Voltage drop across } x) \text{ since } V_3=0 \\ \text{Similarly } \mu V &= [(\text{Voltage drop across } (R+R_0))] + V_3 \\ &= (\text{Voltage drop across } R+R_0) \end{aligned}$$

The current through x must equal the current through $R+R_0$, for since $V_3=0$, no current flows through $(KR+KR_0)$.

$$\begin{aligned} \frac{V}{x} &= \frac{\mu V}{R+R_0} \\ x &= \frac{R+R_0}{\mu} \end{aligned}$$

This means that if x is given the value

$$\frac{R+R_0}{\mu}$$

and a voltage is applied to the circuit in series with R_0 , no voltage is produced across the feed-back diagonal of the bridge. (That is, V_3 in Fig. 3A is zero.) This does not apply to distortion voltages, since these are present in the plate circuit, but not in the grid circuit; i. e., only one generator is acting. By giving x the value

$$\frac{R+R_0}{\mu}$$

we have two points (the ends of the feed-back diagonal) across which the potential corresponding to the fundamental or original transmitted wave is zero, and the potential of the distortion or disturbing wave is not zero. Across these points we have voltages corresponding to any disturbance present in the plate circuit which is not present in the grid circuit. We can now operate on the distortion without disturbing the fundamental or original transmitted wave components.

For example, consider Fig. 4 and Fig. 4A. Fig. 4 shows a feed-back amplifier system comprising three vacuum tubes 1a, 1b, and 1c connected in tandem. Connected in series, across the grid and filament of tube 1a, are a resistance 15 and the secondary winding of input transformer 4 which connects circuit 5 with the amplifier. The resistance 15 is sufficiently great to make the impedance of this resistance and the secondary-to-primary impedance of the transformer in series substantially a pure resistance R_T . The tube 1c is connected to the load or work circuit Z, as in the case of the tube 1 of Fig. 3 and the tube

1c of Fig. 3E. As appears clearly from Fig. 4A, the impedance Z forms the output diagonal of the balanced Wheatstone bridge the ratio arms of which are R_0 , KR_0 , KR and R . In the feed-back diagonal of the bridge are a blocking condenser 9, a resistance R_A and the resistance R_T in series with each other and in parallel with a circuit comprising a blocking condenser 9', resistance x , a blocking condenser 16, and the plate-to-filament space path resistance R_{01} of tube 1b in series. Preferably, the admittance of the space current supply path, through battery 6b and choke coil 17, which path is connected across R_{01} , is negligibly small for the frequencies to be amplified. So also is the admittance of resistance 18 which is connected across the feed-back diagonal of the bridge. Biasing potential from battery 8c is applied to the grid of tube 1c through resistances 18 and x in series. The blocking condensers 9 and 9' prevent plate battery 6c from applying potential to the grids of tubes 1a and 1c, and prevent grid biasing batteries 8a and 8c from applying potentials to the grids of tubes 1a and 1c, respectively. A resistance 19 across circuit 5, and the primary-to-secondary impedance of transformer 4, in parallel, approximately match the impedance of that circuit.

In the circuit of Fig. 4 there will be no feed-back of the fundamental or undistorted wave from the last tube 1c to the first tube 1a, if x has been given the proper value so that there is no fundamental or undistorted voltage across the feed-back diagonal of the bridge. It can be shown that the value obtained for x in the above demonstrations holds when R_A and R_T and 1a and 1b are added to the circuit of Fig. 3C. However, the distortion introduced in the last stage will be reduced, as can be seen from the following consideration of Fig. 4A.

Let the distortion voltage acting in the plate circuit of the last tube be $\mu_0\theta$ after its reduction caused by feedback in the last tube as explained in the case of the tube of Fig. 3 but before any reduction due to feed-back from the last tube to the first tube as about to be explained. There will be some distortion voltage V_0 , impressed on the grid of the first tube as a result of the distortion produced in the last tube and V_0 sets up a driving voltage $\mu_1 V_0$ that may be represented as a generator $\mu_1 V_0$ in the plate-to-filament space path of the second tube. This impresses a voltage tV_0 on the grid of the last tube, which sets up a driving distortion voltage $\mu_0 tV_0$ that may be represented as a generator $\mu_0 tV_0$ in the plate-to-filament space path of the last tube.

Since x has been given such a value that the contribution of any voltage acting in series with R_{01} to V_3 is zero, V_0 is dependent solely on $\mu_0\theta$.

That is

$$V_0 = \mu_0\theta \left[\frac{\frac{R_T}{R_A + R_T}}{\left(\frac{1+K}{K}\right) + \frac{R_0 + R}{(x + R_{01})(R_A + R_T)}} \right]$$

or designating the bracket in this expression β_2

$$V_0 = \mu_0\beta_2\theta.$$

These specific values for V_0 and β_2 follow directly from the configuration of the specific circuit shown, but, though special to that par-

ticular configuration, are given in order to present a concrete illustration of the significance of V_0 and β_2 .

Then

$$\begin{aligned}\mu_0 t V_0 &= \mu_0 t \mu_0 \beta_2 \Theta \\ \mu_0 \Theta - \mu_0 t V_0 &= \mu_0 \Theta - \mu_0 t \mu_0 \beta_2 \Theta \\ &= \mu_0 \Theta (1 - \mu_0 \beta_2 t)\end{aligned}$$

That is, the new driving distortion voltage ($\mu_0 \Theta - \mu_0 t V_0$) is equal to the old driving distortion voltage $\mu_0 \Theta$, multiplied by a factor $(1 - \mu_0 \beta_2 t)$. Now if $\mu_0 \beta_2 t = 1$, the distortion vanishes to zero. That is, if the product of the voltage amplifications and diminutions around the circuit is 1, and the phase shift is 180° , the distortion voltage is balanced out. The amount of improvement in distortion in this circuit (over and above the improvement caused by feedback in merely the last tube) 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 to the first stage, and amplified through the tubes again returns to the plate-filament space path of the last stage with its original amplitude but with its phase shifted 180° .

This operation of this circuit differs from that of Fig. 3 and Fig. 3E, in that the improvement in crosstalk in those circuits is obtained by continued regeneration of the distortion voltage, instead of by the balancing operation described above. In those circuits, and in the circuit of Fig. 6 described hereinafter, it is neither necessary nor probable that the voltage fed around the circuit will be equal to that originally present. The operation just mentioned in the circuit of Fig. 4 may be considered a single regeneration, with the voltage being fed around the circuit once, and coming back in opposite phase to that originally present.

The expressions "continued regeneration" and "single regeneration" as just used in reference to the feed-back amplifiers of Figs. 3, 3E, 4 and 6, are in accordance with the usual explanation of the operation of feed-back amplifiers, of which it is usually said, with reference to positive feed-back action respecting the fundamental frequency, that the operation wherein the energy of the output circuit and the input circuit react upon each other repeats itself a number of times with cumulative effect. However, it is preferred to express the above noted difference in operation of a circuit such as that of Fig. 4 from circuits such as those of Fig. 3 and Fig. 6 by stating that in Fig. 4 the amplified, isolated distortion components fed to the input circuit of the tube 1c do not cause the magnitude of the isolated distortion components (appearing across the input diagonal of the bridge) to be altered, whereas in Figs. 3 and 6 the distortion components fed back to the grid of the last tube cause reduction of the magnitude of the distortion components (that appear across the feedback diagonal of the bridge).

Fig. 5 shows a three-stage feed-back amplifier system similar to that of Fig. 4, but modified in that instead of feeding the isolated distortion components (obtained across the feed-back diagonal of the Wheatstone bridge) back to the grid of the first stage or tube 1a and amplifying the distortion components and the signal components together in that tube before passing them on to the grid of tube 1b, those isolated distortion components 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. Thus, in the system of Fig. 5 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. The number of phase reversing amplifying stages (or other phase reversing means) in the path through which the distortion components are passed in their transmission from the feed-back diagonal of the bridge to the grid of tube 1c should be even. Thus, in this path, the number of phase reversing means or stages (such for example as that comprising tube 1b) in which the signal components and the distortion components are amplified alike should be odd or even according to whether an odd or an even number of phase reversing means or stages (such as that comprising the tube 1d) are used in which the signal is not amplified as the distortion components are.

In Fig. 5 the space current for tube 1c is supplied from battery 6c through a choke coil 20 of negligibly low admittance for the frequencies of the waves to be amplified, the current returning to battery 6c through resistance KR_0 . Condensers 11, 12, 13 and 14 as well as condensers 9, 9' and 16, are stopping or blocking condensers which have negligibly low reactance at the frequencies to be amplified. If desired, the resistance KR_0 may be adjustable, as shown, to facilitate balancing the Wheatstone bridge, the ratio arms of which are formed by the plate-to-filament space path resistance R_0 of tube 1c and the resistances KR_0 , KR and R . The adjustment of KR_0 can be made to correct unbalance resulting 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. The impedance of the feed-back diagonal of the bridge can be adjusted by a variable resistance 25 connected in parallel with a path comprising condenser 9', resistance x (shown adjustable), and plate-to-filament space path resistance R_{01} of tube 1b in series. Also in parallel with the resistance 25 is a path, of negligibly low admittance at the frequencies of the waves to be amplified, extending through stopping condenser 9, input or coupling resistance R_T for tube 1d, and grid biasing battery 8d for that tube, in series. In parallel with R_{01} is a path through choke coil 17 and battery 6b in series, and also a path through grid biasing battery 8c and input or coupling resistance 18' for tube 1c. The two latter paths are of negligibly low admittance at the frequencies of the waves that are to be amplified. However, if desired, the magnitude of the combined resistance of these two paths and the space path of tube 1b may be used as the magnitude R_{01} in the formulae above. The resistance R_T in Fig. 5 corresponds to the resistance R_T in Figs. 4 and 4A and receives the voltage V_0 indicated in Fig. 4A. In Fig. 5 there is no resistance corresponding to the resistance R_A in Figs. 4 and 4A; or in other words the resistance R_A is zero for Fig. 5. The battery 6b supplies space current for tube 1d through choke coil 26. Tube 1d feeds back to the grid of tube 1b through condensers 31 and 32 and resistance 33 in series. This resistance adjusts the voltage thus fed to that grid; and these condensers adjust the phase of that voltage, the capacity of condenser 32 being variable and relatively large compared to that of condenser 31 to

facilitate close or fine adjustment of the phase. As indicated above, the tube 1d in Fig. 5 corresponds to the tube 1a of Figs. 4 and 4A as regards amplification of the distortion voltage V_0 .

- 5 This voltage sets up the driving distortion voltage $\mu_1 V_0$ in the path R_{01} , i. e., in the plate-to-filament space path of tube 1b in Fig. 5, just as explained above for the case of Figs. 4 and 4A. This impresses the voltage tV_0 on the grid of the
10 last tube 1c, which sets up the driving distortion voltage $\mu_0 tV_0$ in the plate-to-filament space path of tube 1c. As in the case of Fig. 4, the resistance x has such a value that the contribution of any voltage acting in series with R_{01} to the voltage V_3 across the feed-back diagonal of the bridge is zero, so that V_0 is dependent solely on $\mu_0 \theta$, the original distortion voltage in the plate-to-filament space path of tube 1c.

- In an amplifier system substantially as shown
20 in Fig. 5, if tube 1c in that figure be regarded as representing four tubes in parallel, the feed-back action reduced the energy contained in the second harmonic to 1/2,250,000 of its value without the feed-back action, and reduced the energy
25 of the third harmonic to 1/50,200 of its value without the feed-back action. This result entailed no sacrifice of overall gain or ultimate level. Feed-back action of the type described for Fig. 3 tends to reduce the gain of the last stage (represented by tube 1c); but the circuit of the
30 type shown in Fig. 5 preferably is operated with this tendency to gain reduction in the stage comprising tube 1c not very pronounced, and with great reduction of distortion by the balancing operation of the type described for Fig. 4. The gain of the first two stages, comprising tubes 1a and 1b, can be large, this portion of the amplifier serving as a voltage amplifier for stepping up the
35 voltage to the power stage represented by tube 1c. The reason why the reduction of the second harmonic is greater than the reduction of the third harmonic (as appears from the ratios given above), is primarily that although the second harmonic (and all even power harmonics)
40 originated by distortion in the penultimate tube 1b, and also all even power sum and difference frequency components or waves so originated, are reduced by neutralizing or counteracting them (as described for the circuit of Fig. 4) with the
45 corresponding distortion waves produced by distortion in the last stage comprising tube 1c, such balancing out does not occur for odd order harmonics or other distortion arising from the presence of odd power terms in the amplifier
50 characteristic. The reasons for this difference will be apparent from the explanation given, for example, in U. S. patents to H. S. Read, 1,464,111, August 7, 1923 and H. Nyquist 1,570,770, January 26, 1926, of the operation of tandem amplifiers in reducing distortion waves originating in the amplifiers.

- The preferable practice, in operation of the circuit of Fig. 5, is to adjust the value of x so that the amplitude of the fundamental in the
65 work circuit is the same for operation of the system with feedback as for operation without feedback. The operation without feedback is obtained by disconnecting the right-hand side of condenser 31 from the junction of the choke
70 coil 26 and the plate of tube 1d and connecting it instead to ground through a passive impedance, not shown, equal to the resistance of the plate-to-filament space discharge path in tube 1d. To make the distortion components balance out in
75 the space path of the last amplifier as explained

in connection with Fig. 4, that is to make $\mu_0 \theta = \mu_0 tV_0$, the magnitude of the feed back distortion components appearing across the feed-back diagonal of the bridge is controlled by adjusting resistance 25 in that diagonal, and the
5 phase shift in tubes 1d, 1b and 1c and their associated circuits is compensated for by phase correcting means, as for example by condenser 32 which can be adjusted to give the desired
10 phase correction. 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. With the circuit of Fig. 5 operated in the manner just described, although the third harmonic is not reduced below
15 the value produced in the penultimate stage, the reduction of the third harmonic originated by distortion in tube 1c is a very great improvement. Since the next to last stage (tube 1b) is operating at relatively low power level, and as a
20 voltage amplifier working into a high impedance, the modulation that it produces is very small, and has generally been considered negligible.

Fig. 6 shows a feed-back amplifier somewhat related to the amplifiers of Fig. 3 and Fig. 3E,
25 and also to the amplifiers of Figs. 4 and 5, yet having important differences from those four amplifiers as regards operation. The system of Fig. 6 comprises the tubes 1a, 1b and 1c connected in tandem, and an auxiliary tube 1e for
30 amplifying only distortion waves, as described hereinafter. Connected in series, across the grid and filament of tube 1a, are a resistance 15' and the secondary winding of input transformer 4 which connects circuit 5 with the amplifier. The
35 resistance 15' is sufficiently great to make the impedance of this resistance and the secondary-to-primary impedance of the transformer in series substantially pure resistance R_{01} . Other considerations entering into the determination of a suitable value for the resistance 15' will be referred to hereinafter. The tube 1c is connected to the load
40 or work circuit Z, as in the case of the tube 1 of Fig. 3 and the tube 1c of Figs. 3, 3E, and 4. As in those four figures, the impedance Z forms the output or work circuit diagonal of the balanced Wheatstone bridge the ratio arms of which are R_0 , KR_0 , KR and R . In the feed-back diagonal of the bridge is a path comprising blocking
45 condenser 9', resistance x , and resistance R_{01} in series. In parallel with this path is a path of negligibly low admittance to waves of the frequencies to be amplified, which comprises blocking
50 condenser 9, input or coupling resistance R_T for tube 1e and grid biasing battery 8a in series. Battery 8a supplies grid biasing potential for tube 1e as well as for tube 1a. Battery 6a supplies plate potential for tube 1e as well as for
55 tube 1a. The resistance R_T in Fig. 6 corresponds to the resistance R_T in Figs. 4, 4A, and 5, and receives the voltage V_0 indicated in Fig. 4A. In Fig. 6, as in Fig. 5, there is no resistance corresponding to the resistance R_A in Figs. 4 and 4A;
60 or in other words the resistance R_A is zero for Fig. 6. Tube 1e feeds, in parallel with tube 1a, into the grid or input circuit of tube 1b.

As in the case of the resistance x in Figs. 4 and 5, the resistance x in Fig. 6 is given such a value
70 that the contribution of any voltage acting in series with R_{01} to the voltage V_3 (see Fig. 4A) across the input diagonal of the bridge is zero, so that V_0 (which is the voltage across R_T) is dependent solely on $\mu_0 \theta$, the original distortion
75

voltage in the plate-to-filament space path of tube 1c. That is,

$$x = \frac{R + R_0}{\mu}$$

where μ represents the amplification from a voltage across the grid of the auxiliary tube 1e to a driving voltage in the plate-to-filament space path of tube 1c. Thus, as explained in connection with Fig. 4, the value of x is such that the fundamental or original transmitted wave components have zero voltage across the feed-back diagonal of the bridge, i. e., across the grid and filament of tube 1e. Thus, theoretically at least, the auxiliary tube 1e, as in case of the auxiliary tube 1d in Fig. 5, amplifies only distortion waves and no fundamental or original transmitted wave components. A valuable feature of the circuit of Fig. 6 is that, as in Fig. 5, the fundamental or original transmitted wave components are not regenerated through the auxiliary tube, and consequently the gain reduction that such regeneration would entail if it occurred is obviated. Distortion waves are regenerated (negatively), in a manner analogous to that in which they are regenerated (negatively) in Figs. 3 and 3E, through tubes 1e, 1b, and 1c. Thus, there results a reduction of distortion, the magnitude of the reduction depending on a factor $1 + \mu\beta_1'$, where μ represents the voltage amplification, and β_1' the voltage diminution, around the circuit through tubes 1e, 1b and 1c or through the path comprising the auxiliary amplifier and that portion of the signal amplifier forming with the auxiliary amplifier a regeneration circuit for distortion waves. (β_1' here corresponds, in connection with Fig. 6, to β_1 and β_2 referred to above in connection with Figs. 3 and 4, respectively.) The number of phase reversing means, as for example, amplifying stages, in this path should be odd, but the number of amplifying stages in it may be as great as desired; so the reduction of distortion can be as great as is necessary. Moreover, as long as the number of phase reversing means in this path is maintained odd, the auxiliary amplifier may have any desired number of stages, the number of stages of the signal amplifier used in this path being then made any desired number which will make the total number of phase reversing means in this path odd. For example, tube 1e may be replaced by three tubes in tandem. In cases where, for the desired degree of reduction of distortion, this path requires a greater number of stages than would be available for it in the signal amplifier as designed without reference to suppression of distortion by feed-back action, it will ordinarily be advisable to use a plurality of stages in the auxiliary amplifier rather than to increase the number of stages in the signal amplifier; for ordinarily the operating requirements for the auxiliary amplifier, with respect to load capacity and constancy of power supply voltages, impedance and gain, for example, are much less severe than those for the signal amplifier. Since the only load carried by the auxiliary amplifier is the light load of the distortion waves, it originates very little distortion.

In the system of Fig. 6, as well as in that of Fig. 3, the feed-back action increases load carrying capacity, decreases distortion, and increases stability of gain with tube and power changes.

In Fig. 4, neither distortion components nor fundamental or original transmitted wave components are regenerated, except in the last

tube. However, the distortion components are fed back around the circuit once. The reduction of distortion in the system of Fig. 4 depends primarily on how well the amplitude and voltage of the two opposing voltage waves are adjusted. The overall gain of the circuit need not be reduced, although the gain of the last tube is reduced somewhat.

In Fig. 6, in the auxiliary tube or tubes used to amplify the distortion, only the distortion components are regenerated, and not the fundamental or original transmitted wave components. Thus, the improvement with respect to distortion, load capacity and gain stability does not depend upon sacrifice of the gain of the amplifier. Both the distortion components and the fundamental or original transmitted wave components are regenerated (negatively) through the path comprising the signal transmitting tubes 1a, 1b and 1c; but the consequent reduction of gain can be made small since not this regeneration but the regeneration of the distortion waves through the path including the auxiliary amplifier, is the regeneration preferably relied upon to produce the principal reduction of distortion. In order to obviate large gain reduction caused by regeneration through tubes 1a, 1b and 1c, the ratio $R_{01}/(R_{01} + x)$ is preferably made small. However, as explained above, 15' should be sufficiently large for proper phase control. Moreover, R_{01} is preferably small. For if $R_{01}/(R_{01} + x)$ is to be small, R_{01} should be small unless x can be large; and the larger x is made, the smaller becomes μ , since $x = (R + R_0)/\mu$. It is advantageous to make R large both because increase of R tends to increase μ and because increase of R tends to increase the stability of operation of the system, especially as regards gain and distortion elimination as affected by variation in plate and filament voltages and other circuit variables.

Each of the systems shown in Figs. 3, 4 and 6 is typical of a wide variety of possible circuits. The principles of operation described for any one or two or all three of these three types of circuits are applicable in general to devices capable of amplifying waves, for improvement of their operation. These principles are of very broad and general application. Their application is by no means limited to operation intended to be mere amplification. The theory of these systems has been checked by careful tests of physical embodiments of the systems. Each of these systems reduces both odd order and even order distortion components at the same time, and can stabilize gain and afford high load capacity.

One difference between Fig. 4 on the one hand and Figs. 3 and 6 on the other hand, lies in the relative seriousness of unavoidable phase shifts in the amplifier. Since the effectiveness of Fig. 4 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°, and that the gain of the circuit change very little after a balance is once attained. However, in Figs. 3 and 6, the improvement depends on the factor

$$\frac{1}{1 + \mu\beta}$$

β indicating a factor such as β_1 or β_1' (or β_2) mentioned above.

If originally

$$\mu\beta = 10 + j0, \quad \frac{1}{1 + \mu\beta} = .0909$$

an improvement of 20.8 db. If we assume the gain to change by 3 db so that $\mu\beta=7+j0$, then

$$\frac{1}{1+\mu\beta}=.125$$

an improvement of 18.0 db. A similar change in gain in Fig. 4 would change an infinite improvement to a 10.4 db improvement. Similarly, if $\mu\beta=7.07+j7.07$ (absolute magnitude the same, but at a 45° angle)

$$\frac{1}{1+\mu\beta}=.1075$$

an improvement of 19.35 db. A similar shift of 45° in Fig. 4 would change an infinite improvement to a 2.3 db improvement.

An important capability of the circuit of Fig. 5 is that the improvement in distortion can be augmented or made cumulative, by extending the circuit to form that of Fig. 7. A second bridge circuit is formed, with a ratio arm constituted by the network that faces the output diagonal of the first bridge. In this arm, therefore, is a voltage proportional to the residue of distortion remaining after the first balancing. The fundamental or original transmitted wave components are also present in this arm. The other three ratio arms of the second bridge are $K'R'$, $K'R$, and R' , corresponding respectively to the ratio arms KR , KR , and R of the first bridge. The output or work circuit diagonal of the second bridge is the condenser 11 and the primary-to-secondary impedance of amplifier output transformer 2 in series. The resistance x' corresponds in function to resistance x , and is of such magnitude that the voltage of the fundamental or original transmitted wave components across R_{01} and x' in series (i. e., across the feed-back diagonal of the second bridge) is zero. Thus the primary winding of a transformer 35, which is connected across the feed-back diagonal of the second bridge, receives only a voltage proportional to the residue of distortion just mentioned. This voltage is amplified in amplifier 1'd and the amplified voltage is fed through resistance 33' and condenser 31' to the grid or input circuit of tube 1b. It is apparent that the residue of distortion just mentioned is isolated from the fundamental components and fed back in the same fashion as the first process. Thus the distortion is again improved by approximately the same ratio as before. In balancing circuits which have heretofore been used for reducing distortion (such as the Colpitts push-pull circuit), only one improvement can be achieved, and that only for odd order or even order distortion components and not for both odd order and even order components at the same time; whereas the improvement obtained with the circuit of Fig. 5 can be multiplied as many times as desired by adding bridges in tandem as indicated in Fig. 7, each additional bridge reducing both odd order and even order distortion components and reducing the distortion by approximately the same factor as the circuit with only the first bridge.

In Fig. 7 the elements 9', 12', 13', 25', 26', 31', 33' and 1'd are similar in structure and function to the elements 9, 12, 13, 25, 26, 31, 33 and 1d, respectively, and the primary-to-secondary impedance $R_{T'}$ of transformer 35 is connected across the feed-back diagonal of the second bridge as the impedance R_T is connected across the feed-back diagonal of the first bridge.

The circuit of Fig. 6 can be made cumulative in

its action by extending it to form the circuit of Fig. 8, in a manner similar to that described for making the circuit of Fig. 5 cumulative in its action by extending it to form the circuit of Fig. 7. In Fig. 8, as in the case of Fig. 7, a second bridge circuit is formed, with a ratio arm constituted by the network that faces the output diagonal of the first bridge. In this arm, therefore, is a voltage proportional to the residue of distortion remaining after the first balancing. The fundamental or original transmitted wave components are also present in this arm. The other three ratio arms of the second bridge are $K'R_{01}$, $K'R'$, and R' , respectively. The output diagonal of the second bridge is the primary-to-secondary impedance of amplifier output transformer 2. The resistance x' corresponds in function to the resistance x , and is of such magnitude that the voltage of the fundamental or original transmitted wave components across R_{01} and x' in series (i. e. across the feed-back diagonal of the second bridge) is zero. Thus, the tube 1'e, which has its input or coupling resistance $R_{T'}$ connected across the input corners of the second bridge diagonally opposite each other, receives only a voltage proportional to the residue of distortion just mentioned. This voltage is amplified in amplifier 1'e and the amplified voltage is fed to the grid or input circuit of tube 1b. It is apparent that the residue of distortion just mentioned is isolated from the fundamental components and fed back in the same fashion as the first process. Thus, the distortion is again improved by approximately the same ratio as before. As explained in connection with Fig. 7, as many bridges as desired may be connected in tandem in a circuit such as that of Fig. 8.

Fig. 9 shows an amplifier circuit in which distortion waves are isolated and fed back in a manner similar to that described for the circuit of Fig. 6, but instead of an auxiliary tube for amplifying the isolated distortion waves an auxiliary grid or space discharge control electrode 41 in signal amplifying tube 1'c is employed, the isolated distortion waves obtained across x and R_{01} in series (i. e. across the feed-back diagonal of the Wheatstone bridge) being impressed on grid 40 through the blocking condenser 9 and amplified in tube 1'c. The distortion waves are isolated from the signal waves by adjusting the value of x as explained above so that across the path through x and R_{01} in series the voltage of the fundamental or original transmitted wave components is zero. A battery 8'c supplies biasing potential to the grid 41 through a choke coil 42 which has negligibly low admittance at the frequencies to be amplified. This potential is ordinarily a positive potential as is usually the case for the auxiliary or second grid of a four-electrode tube used to amplify two waves impressed on its main and auxiliary grids, respectively.

Fig. 10 shows a feed-back amplifier especially suitable for use in amplifying a plurality of messages simultaneously, as for example an amplifier in a line over which multiplex carrier telephone transmission is effected. This amplifier operates to reduce distortion in the general manner explained in connection with Fig. 6. However, the system of Fig. 10 comprises five stages of signal amplifying tubes in tandem and two amplifier stages in the auxiliary amplifier for amplifying distortion waves only. The first, second, third and fourth stages of signal amplifying tubes comprise tubes 51, 1a, 1b, and 1'b, respectively. The

fifth stage comprises tubes $1c_1$ and $1c_2$ in parallel with each other and tubes $1c_3$ and $1c_4$ in parallel with each other, the pair $1c_1$ and $1c_2$ being in push-pull relation to the pair $1c_3$ and $1c_4$. The first and second stages of the auxiliary amplifier comprise tubes $1e$ and $1'e$ respectively.

Filament heating current is supplied from battery 7 through choke coil 52 to a path comprising the filaments of tubes $1b$ and $1'e$ in parallel with each other and in series with the filaments of tubes $1'b$, $1c_2$ and $1c_1$. Filament heating current is supplied from battery 7' through choke coil 52' to a path extending through the filament of tube 51 and a resistance 53 in parallel, thence through the filaments of tubes $1a$ and $1e$ in parallel, and thence through the filaments of tubes $1c_3$ and $1c_4$ in series.

Biassing voltage, obtained as the voltage drop across the filaments of tubes $1a$ and $1e$ and tube $1c_3$, is applied to the grid of tube 51 through the secondary winding of input transformer 4 which couples circuit 5 to tube 51 . Biassing voltage, obtained as the voltage drop across the filaments of tubes $1c_3$ and $1c_4$, is applied to the grid of tube $1a$ through the secondary winding of an inter-stage transformer 54 through which tube 51 feeds tube $1a$, and is applied to the grid of tube $1e$ through resistance R_r . Biassing voltage, obtained as the voltage drop across the filaments of tubes $1'b$ and $1c_2$, is applied to the grid of tube $1b$ through input or coupling resistance 56, and is applied to the grid of tube $1'e$ through the secondary winding of transformer 57 through which tube $1c$ feeds tube $1'e$. Across coil 52 and battery 7 is connected a resistance 55, and across coil 52' and battery 7' is connected a resistance 55'. The positive poles of grid biasing batteries 8 and 8' are adjustably connected to resistances 55 and 55', respectively. Biassing potential from a point on battery 8 is applied to the grid of tube $1'b$ through the secondary winding of an inter-stage transformer 64 through which tube $1b$ feeds tube $1'b$. Biassing potential from a point on battery 8 is applied to the grid of tube $1c_1$ through a secondary coil 66 of a transformer 65 through which tube $1'b$ feeds tubes $1c_1$, $1c_2$, $1c_3$ and $1c_4$. Biassing potential from a point on battery 8 is applied to the grid of tube $1c_2$ through a secondary coil 67 of the transformer 65. Biassing potentials from points on battery 8' are applied to the grids of tubes $1c_3$ and $1c_4$ through secondary coils 68 and 69, respectively, of the transformer 65.

Plate potential for tubes 51 , $1a$ and $1e$ is supplied from plate battery 6 through the primary winding of transformer 54, a choke coil 71 and the primary winding of transformer 57, respectively. Plate potential for tubes $1b$ and $1'e$ is supplied from this battery through the primary winding of transformer 64. Plate potential for tube $1'b$ is supplied from this battery through the primary winding of transformer 65.

Plate potential for tubes $1c_1$ and $1c_2$ is supplied from plate battery 6c by a circuit extending through a choke coil 72, the upper half of primary winding of transformer 2, and thence through a path having a branch KR_0 in parallel with a branch comprising a resistance KR and the upper half of the primary winding of a transformer 73.

Plate potential for tubes $1c_3$ and $1c_4$ is supplied from plate battery 6c by a circuit extending through a choke coil 72', the lower half of primary winding of transformer 2, and thence through a path having a branch KR_0 in parallel with a branch comprising a resistance KR and the lower

half of the primary winding of the transformer 73.

The impedance of the plate-to-filament space path of each of the tubes $1c_1$, $1c_2$, $1c_3$ and $1c_4$ is $2R_0$. Thus, the impedance of the space paths of tubes $1c_1$ and $1c_2$ in parallel is R_0 . This impedance R_0 forms one of the ratio arms of a network which can be regarded as a balanced Wheatstone bridge, the other three ratio arms of which are R , KR and KR_0 , and one diagonal of which is the upper half or coil of the primary winding of transformer 73. This diagonal is the feed-back diagonal of this bridge.

The impedance of the combined space paths of tubes $1c_3$ and $1c_4$ in parallel is R_0 . This impedance R_0 forms one of the ratio arms of a network which can be regarded as a balanced Wheatstone bridge, the other three ratio arms of which are R , KR and KR_0 , and one diagonal of which is the lower half or coil of the primary winding of transformer 73. This diagonal is the feed-back diagonal of this bridge. As can be seen from the symmetry of the two bridge circuits in Fig. 10, blocking condenser 11 as well as the junction of the two resistances R is at ground potential for A. C. Consequently, the upper and lower coils of the primary winding of transformer 2 can be regarded as diagonals (output diagonals), respectively, of the bridges which have the upper and lower coils of the primary winding of transformer 73 as their feed-back diagonals.

The designation of the plate impedance of each of tubes $1c_1$, $1c_2$, $1c_3$ and $1c_4$ as $2R_0$ is not to indicate that these impedances are higher than those of tubes described above as having plate impedance R_0 , but is to facilitate comparison of the bridge circuits of Fig. 10 with those of other figures of the drawings.

The resistance of the plate-to-filament space path of tube $1a$ is R_{01} . A path comprising this impedance and resistance x in series is connected across the secondary winding of transformer 73, through blocking condenser 9'. In parallel with this path is a path of negligibly low admittance to waves of the frequencies to be amplified, which comprises blocking condenser 9 and input or coupling resistance R_r for tube $1e$ in series. The shunt across R_{01} through choke coil 71 and battery 6 has negligibly low admittance at the frequencies of the waves to be amplified. The resistance R_r in Fig. 10 corresponds to the resistance R_r in Fig. 6, and receives the voltage V_0 indicated in Fig. 4A from the secondary winding of transformer 73. The auxiliary amplifier comprising tubes $1e$ and $1'e$ in tandem feeds, in parallel with tube $1b$, into the grid or input circuit of tube $1'b$.

As in the case of the resistance x in Fig. 6, the resistance x in Fig. 10 is given such a value that the contribution of any voltage acting in series with R_{01} to the voltage V_3 (see Fig. 4A) across R_{01} and x in series, is zero, so that V_0 (which is the voltage across R_r) is dependent solely on $\mu_0\theta$, the original distortion voltage in the plate-to-filament space path of each of the tubes $1c_1$, $1c_2$, $1c_3$ and $1c_4$. Thus, as explained in connection with Fig. 6, the value of x is such that the fundamental or original transmitted wave components have zero voltage across the grid and filament of tube $1e$. Thus, theoretically at least, the auxiliary amplifier comprising tubes $1e$ and $1'e$, as in the case of the auxiliary amplifier tube $1e$ in Fig. 6, amplifies only distortion waves and no fundamental or original transmitted wave components. Distortion waves are regenerated, in a manner analogous to that in which

they are regenerated in Fig. 6, through tubes 1e, 1'e, 1'b and the push-pull stage comprising tubes 1c₁, 1c₂, 1c₃ and 1c₄. Thus, there results from the feedback action a reduction of the distortion produced in the tubes of the last stage, as in the case of Fig. 6, and also, as in the case of that figure, increase of load capacity, and increase of stability of gain with tube and power changes. In Fig. 10, as in Fig. 6, the improvement in these respects does not depend upon sacrifice of the gain of the amplifier.

Circuit 3 is fed from the amplifier through the transformer 2. The voltage across the path consisting of the two halves or coils of the primary winding of the transformer and blocking condenser 11 in series, is the sum of that across R and KR in the Wheatstone bridge which has the space path of tubes 1c₁ and 1c₂ as one of its ratio arms and that across R and KR in the Wheatstone bridge which has the space path of tubes 1c₃ and 1c₄ as one of its ratio arms. In each of these bridges, with respect to A. C. the output diagonal or work circuit diagonal can be regarded as terminating at the cathode of the discharge path included in a ratio arm of the bridge, the feed-back diagonal terminating at the anode of the path; whereas in the bridge in the other figures, the feed-back diagonal terminates at the cathode and the output or work circuit diagonal terminates at the anode.

As is ordinarily the case in output transformers for push-pull amplifiers, the coils of the primary winding of transformer 2 are so wound and connected that the output circuit 3 receives the cumulative effect of the output of fundamental or original transmitted wave from the tubes which feed these coils. Similarly, the resistance RT can receive the cumulative effect of the output of fundamental or original transmitted wave and odd harmonics from the tubes 1c₁, 1c₂, 1c₃ and 1c₄. The distortion components fed back to RT are fed back as described above in connection with Fig. 6, to reduce those components as appearing in the work circuit 3.

Fig. 11 is a set of curves plotted from observed data, showing the output of second and third harmonics as functions of output of the fundamental or original transmitted current, for a system of the type of that shown in Fig. 5. The curve for the second harmonic taken with regeneration shows that with an output of fundamental up to 30 milliamperes into an impedance of 600 ohms, the power level of the output of second harmonic is 90 decibels below the power level of the output of fundamental. This means that the fundamental power is about 900,000,000 times as great as the power of the second harmonic, and that the current ratio of fundamental to second harmonic is about 30,000. The curve for the second harmonic taken without feedback shows that up to 30 milliamperes output of fundamental the output of second harmonic is only about 30 db. lower than the output of fundamental (i. e., the power output of fundamental is only about 900 times as great as the power output of second harmonic, instead of 900,000,000 times as when feedback is employed). For current outputs greater than 30 milliamperes of fundamental, the curve for the second harmonic for operation with feedback is still well above the curve for the second harmonic for operation without feedback. Likewise, the curves for the third harmonic taken with and without feedback show great reduction of the ratio of that harmonic to the fundamental, as a result of the feedback.

Moreover, similar important reduction of the output levels of other harmonics, both odd and even, (and also of the output levels of intermodulation products), as compared to the output levels of the fundamental waves, is effected by the feedback. The curves for both harmonics for operation without feedback are for operation corresponding to operation of the circuit of Fig. 5 with the right hand side of condenser 31 disconnected from the junction of the choke coil 26 and the plate of tube 1d and connected instead to ground through a passive impedance (not shown) equal to the resistance of the plate-to-filament space discharge path in tube 1d.

Fig. 12 is a set of curves plotted from observed data, showing the overall gain as a function of current output into a 600 ohm resistance, for the fundamental, in a specific system of the type of that shown in Fig. 5. Below about 30 milliamperes of output current the solid line curve, which is for operation with feedback, substantially coincides with the dotted line curve, which is for operation without feedback. This is in marked contrast to the gain-load curves of Fig. 3D for the circuit of Fig. 3, inasmuch as the feedback in the latter circuit lowers the gain. In Fig. 12 the solid line curve lies well above the dotted line curve, for outputs considerably greater than thirty or forty milliamperes, thus showing great gain stabilization effected by the feedback, this stabilization being effected without gain reduction corresponding to such reduction indicated by Fig. 3D for the circuit of Fig. 3.

It is desired to emphasize the fact that the invention 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 feedback 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 in each of the amplifying systems described herein the invention 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. If in Fig. 6, for example, a wave of a given fundamental frequency is amplified in any or all of tubes 1a, 1b and 1c (or the circuits associated with the tube or tubes) to a degree less than, say, the normal amplification for the tube or tubes (and the associated circuits) then for that frequency the feed-back voltage, or regenerated voltage across the feed-back diagonal of the bridge tends to be lower than normal, i. e., less than the fundamental which is applied there from circuit 5 through R₀₁ 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 tubes 1a, 1b and 1c, then for that

frequency the feed-back voltage tends to be higher than the voltage of that frequency which is applied across the feed-back diagonal by circuit 5 through R_{01} 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.

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 Wheatstone bridges, or as input diagonals of the bridges. However, the invention is not limited to the case in which these impedances are 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). This is indicated by Figs. 3F, 4B and 6A, which are like Figs. 3, 4 and 6 respectively, except that Z_0 , KZ_0 , KZ_2 , Z , Z_1 , Z_0 , Z_A and Z_T replace R_0 , KR_0 , KR , R , x , R_{01} , R_A and R_T , respectively. These replacements may likewise be made in the mathematical formulae and expressions above. Moreover, as indicated in the above description of Fig. 10, and as further indicated by Fig. 9A, in any of the figures of the drawings the bridge arms R and KR_0 , (or Z and KZ_0), may be interchanged in their positions in the bridge. In any of the figures of the drawings the impedance Z_0 includes the tube internal plate-to-filament capacity. 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. In combination, wave translating apparatus, means for applying to said apparatus waves producing modulation in said apparatus, wave balancing and isolating means for deriving, from the modulation components, waves including odd order modulation components to the substantial exclusion of waves produced without frequency change by the applied waves, and means for impressing the derived waves on the input side of said apparatus.

2. In combination, wave translating apparatus, means for applying to said apparatus waves producing modulation in said apparatus, wave balancing means for deriving, from the modulation components, waves including odd order modulation components to the substantial exclusion of waves produced without frequency change by the applied waves, and means for impressing the derived waves on the input side of said apparatus in such phase as to reduce the magnitude of the modulation components produced in said apparatus.

3. A system comprising an electric space discharge device having an anode, a cathode and a discharge control element, means for isolating waves including odd order modulation products produced by said device in response to application to the input circuit of said device of waves of frequency different from the frequency of the first mentioned waves, amplifying means for producing from said isolated waves amplified waves of the same frequency and phase as said isolated waves, and means for feeding said amplified

waves to the input circuit of said device in such sense as to reduce the intensity of the first mentioned waves.

4. In combination, an electric space discharge device having an anode, a cathode and a discharge control element, means for isolating waves produced by said device in response to waves of frequency different from the frequency of the first mentioned waves, a Wheatstone bridge included in said means and having three of its arms passive impedances, and means connecting the space discharge path between said anode and said cathode in the remaining arm of said bridge.

5. In combination, an electric space discharge device having an anode, a cathode and a discharge control element, means for isolating waves produced by said device in response to waves of frequency different from the frequency of the first mentioned waves, a Wheatstone bridge included in said means and having three of its arms passive impedances, means connecting the space discharge path between said anode and said cathode in the remaining arm of said bridge, and means for supplying the second mentioned waves in a diagonal of said bridge.

6. The method of operating wave translating apparatus which comprises applying to said apparatus waves producing modulation in said apparatus, isolating modulation products, supplying the isolated products to the input circuit of the apparatus to alter the magnitude of the modulation products, deriving from the output waves of said apparatus waves of frequencies of the modulation products but exclusive of waves produced without frequency change by the applied waves, and impressing the derived waves on the input side of said apparatus to further alter the magnitude of the modulation products.

7. In combination, wave translating and distorting apparatus, means for applying to said apparatus waves producing in said apparatus distortion components including odd order modulation, wave balancing and isolating means for deriving distortion components including waves of the frequency of said odd order modulation components from distortion components produced in said apparatus, and means for so impressing the derived waves on said apparatus as to alter the intensity of the derived waves.

8. In combination, wave translating apparatus, means for applying to said apparatus waves producing in said apparatus waves including odd and even order products of modulation, wave balancing and isolating means for deriving, from the produced waves, waves of the frequencies of said odd and even order modulation products to the substantial exclusion of waves produced without frequency change by the applied waves, and means for so impressing the derived waves on said apparatus as to alter the intensity of the derived waves.

9. The method of operating wave translating apparatus which comprises applying to the input side of the apparatus waves which produce modulation in the apparatus, balancing waves from the output side of the apparatus against the applied waves to isolate modulation products, amplifying the isolated modulation products alone, and impressing the amplified products on the input side of said apparatus in such manner as to alter the magnitude of the isolated modulation products.

10. In combination, wave translating apparatus comprising an electric space discharge tube having an anode, a cathode and two discharge

control elements, means for supplying to one of said control elements waves producing modulation in said apparatus, and means for isolating modulation products and impressing them on said other control element.

11. The method of operating wave translating apparatus which comprises applying to said apparatus waves producing modulation in said apparatus, isolating modulation products and impressing them on the input side of said apparatus to alter the magnitude of the isolated products and of the modulation products, deriving from the output waves of said apparatus waves of frequencies of the modulation products but exclusive of waves produced without frequency change by the applied waves, and impressing the derived waves on the input side of said apparatus.

12. In a signal wave repeater having input and output circuits, means for reducing distortion comprising means coupling the output and input circuits for odd and even order distortion components but not for the signal components.

13. In combination, a plurality of electric space discharge devices connected in cascade relation, connections for producing negative feed-back of waves from the output circuit of the last one of said devices to the input circuit of that device, and connections for feeding from the first mentioned connections to the input circuit of the first one of said devices distortion components generated in said last one of said devices, to the exclusion of waves originally transmitted through the preceding ones of said devices.

14. The method which comprises so operating upon fundamental waves as to produce a resulting wave containing fundamental components of the frequencies of said fundamental waves and modulation products different from said fundamental components, isolating said modulation products from said fundamental components by balancing said fundamental waves exclusive of other waves against said fundamental components in said resulting wave, and regenerating said modulation products.

15. The method of operating an amplifier circuit which comprises transmitting to said circuit fundamental waves which produce in the circuit a resulting wave that contains fundamental components of the frequencies of said fundamental waves and distortion products different from said fundamental components, isolating said distortion products from said fundamental components by balancing said fundamental waves exclusive of other waves against said fundamental components in said resulting wave, and so regenerating said distortion products in said circuit as to reduce them.

16. A circuit comprising a wave translating device, means for transmitting fundamental waves to said device which produce in said device a resulting wave containing fundamental components that have the same frequencies as said fundamental waves and distortion products differing from said fundamental components, means for so opposing said fundamental waves exclusive of other waves to said fundamental components in said resulting wave as to isolate said distortion products, and means for regenerating in said circuit said distortion products only.

17. A circuit comprising a wave translating device, means for transmitting to said device fundamental waves which produce distortion components in said device, a wave transmission path for transmitting the fundamental waves substantially without distortion and opposing the waves so

transmitted against waves transmitted through said device, said 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 device 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 the distortion components.

18. A circuit comprising a vacuum tube device, means for transmitting to said device fundamental waves which produce distortion components in said device, a wave transmission path for transmitting the fundamental waves, substantially without distortion and opposing the waves so transmitted against waves transmitted through said device, said 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 device and thereby yield the distortion components without fundamental waves, and means for causing only these isolated distortion components to be so regenerated in said circuit as to reduce the amplitude of distortion components delivered by said circuit.

19. The method which comprises so operating upon fundamental waves as to produce a resulting wave containing fundamental components of the frequencies of said fundamental waves and distortion products different from said fundamental components, isolating said distortion products from said fundamental components by balancing said fundamental waves exclusive of other waves against said fundamental components in said resulting wave, amplifying said isolated distortion components in their isolated state, and thereafter amplifying them with said fundamental waves to control the effective magnitude of said distortion products in said resulting wave.

20. A wave translating system comprising a vacuum tube device having a grid, a circuit fed from said device, means for transmitting fundamental waves to said grid, means for deriving from a portion of said circuit a resulting wave containing fundamental components that have the same frequencies as said fundamental waves and distortion products differing from said fundamental components, means for so opposing said fundamental waves exclusive of other waves to said fundamental components in said derived wave as to isolate said distortion products, and means for so feeding said distortion products back to such a portion of said system anterior to said portion of said circuit as to cause the amplitude of said distortion products to be reduced by repeated reamplification in a portion of said system anterior to said portion of said circuit but exclusive of said grid.

21. A vacuum tube having two electrically separate grids, means for transmitting to one of said grids fundamental waves which produce in said device a resulting wave containing fundamental components that have the same frequencies as said fundamental waves and incidental distortion products of frequencies different from their respective fundamental components, means for so opposing said fundamental waves exclusive of other waves to said fundamental components in said resulting wave as to isolate said distortion products, and means for feeding said iso-

lated distortion products to said other grid in such phase as to reduce their magnitude by repeatedly regenerating them in said device.

22. In a signal amplifier having an input and an output circuit, said amplifier having a non-linear relation between output and input waves whereby the amplifier tends to produce distortion in the form of signal modulation components along with the amplified signal, means for reducing the distortion so produced comprising a circuit for feeding back odd order modulation components to the substantial exclusion of signal components from the output circuit to the input circuit opposing the tendency of said amplifier to produce said distortion.

23. In a signal amplifier having an input and an output circuit, said amplifier having a non-linear relation between output and input waves whereby the amplifier tends to produce distortion in the form of signal modulation components along with the amplified signal, means for reducing the distortion so produced comprising a circuit for feeding back odd and even order modulation components to the substantial exclusion of signal components from the output circuit to the input circuit opposing the tendency of said amplifier to produce said distortion.

24. In a signaling system, a line for transmitting waves of a broad band of frequencies, said line divided into sections, an amplifying repeater having an input circuit coupled to an incoming line section and an output circuit coupled to an outgoing line section, said repeater having a non-linear relation between output currents and input voltages whereby the repeater tends to produce components of new frequencies by interaction between different input frequency components within said broad band, and a circuit feeding back some of the output voltages, including odd and even order components of said new frequencies to the substantial exclusion of signal components, from the output circuit to the input circuit in opposing relation whereby the amplitude of the new frequencies appearing in the outgoing line section is reduced.

25. A signal wave repeater comprising an input and an output circuit, means to impress signal waves on said input circuit to be repeated, an outgoing circuit for the repeated waves connected between two points in said output circuit between which a difference of potential of the signaling frequency exists, said output circuit having a branch across which a difference of potential corresponding substantially only to odd and even order products of modulation between the impressed signals is developed, and means for reducing signal distortion in said repeater comprising a circuit connection between said branch and the input circuit for impressing said odd and even order modulation products on said input circuit in such phase as to reduce production of said modulation components in said output.

26. In an amplifier circuit, a space discharge device having an input and an output, a source of waves to be amplified, applied to the input circuit of said device, a load circuit connected to said output in series with an external impedance, a branch circuit connected to said device, said load circuit and said external impedance, across which a difference of potential is developed, representing odd and even order modulation products of said applied waves to be amplified to the substantial exclusion of the waves to be amplified, and means for reducing the amount of modulation produced in said amplifier circuit com-

prising a circuit for applying to the input of said device a portion of the voltage developed in said branch, in a phase to reduce production of modulation in said amplifier circuit.

27. In combination, wave translating apparatus, means for applying to said apparatus waves producing modulation in said apparatus, wave balancing and isolating means for deriving, from the modulation components, waves including odd order and even order modulation components to the substantial exclusion of waves produced without frequency change by the applied waves, and means for impressing the derived waves on the input side of said apparatus.

28. In combination, wave translating apparatus, means for applying to said apparatus waves producing modulation in said apparatus, wave balancing means for deriving, from the modulation components, waves including odd order and even order modulation components to the substantial exclusion of waves produced without frequency change by the applied waves, and means for impressing the derived waves on the input side of said apparatus in such phase as to reduce the magnitude of the modulation components produced in said apparatus.

29. A system comprising an electric space discharge device having an anode, a cathode and a discharge control element, means for isolating waves including odd order and even order modulation products produced by said device in response to application to the input circuit of said device of waves of frequency different from the frequency of the first mentioned waves, amplifying means for producing from said isolated waves amplified waves of the same frequency and phase as said isolated waves, and means for feeding said amplified waves to the input circuit of said device in such sense as to reduce the intensity of the first mentioned waves.

30. An active transducer, a feedback path therefor for feeding back in said transducer distortion components produced from fundamental components by said transducer to the substantial exclusion of the fundamental components, and a second feedback path conjugate to the first mentioned feedback path, for feeding waves back in said transducer.

31. An amplifier and two conjugate paths each feeding back in said amplifier distortion components produced from fundamental components by said amplifier to the substantial exclusion of the fundamental components.

32. A vacuum tube system comprising a vacuum tube having two electrically separate grids, means for transmitting to one of said grids fundamental waves which produce in said system a resulting wave containing fundamental components that have the same frequencies as said fundamental waves and distortion products of frequency different from said fundamental components, means for so opposing said fundamental waves exclusive of other waves to said fundamental components in said resulting wave as to isolate said distortion products, and means for feeding said isolated distortion products to said other grid.

33. A vacuum tube system comprising a vacuum tube having two electrically separate grids, means for transmitting to one of said grids fundamental waves which produce in said system a resulting wave containing fundamental components that have the same frequencies as said fundamental waves and distortion products of frequency different from said fundamental com-

ponents, and means for so feeding said distortion products to said other grid as to reduce the distortion products in said resulting wave.

34. The method which comprises so operating upon fundamental waves as to produce a resulting wave containing fundamental components of the frequencies of said fundamental waves and modulation products different from said fundamental components, isolating said modulation products from said fundamental components by balancing said fundamental waves exclusive of other waves against said fundamental components in said resulting wave, and so regenerating said modulation products that they reappear at their place of origin with their phase reversed.

35. Signaling apparatus comprising a wave translating device, means for transmitting fundamental waves to said device which produce therein a resulting wave containing fundamental components that have the same frequencies as said fundamental waves and distortion products differing from said fundamental components, means for so opposing said fundamental waves exclusive of other waves to said fundamental components in said resulting wave as to isolate said distortion products, and means for so regenerating said distortion products in said device that they reappear at their place of origin in reversed phase.

36. A circuit comprising a wave translating device, means for transmitting to said device fundamental waves which produce distortion components in said device, a wave transmission path for transmitting the fundamental waves substantially without distortion and opposing the waves so transmitted against waves transmitted through said device, said 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 device and thereby yield the distortion components without fundamental waves, and means for causing these isolated distortion components to be so regenerated that they reappear at their place of origin in reversed phase.

37. A system comprising a plurality of stages of electric space discharge devices, means for isolating distortion components produced in signaling waves by their transmission through said devices from signaling components of the waves, said means including paths for balancing waves on the input side of the first device against signaling components of equal amplitude but opposite phase in waves from the output side of the last device, and means for feeding distortion waves resulting from said balancing action through said devices.

38. A system comprising a plurality of stages of electric space discharge devices, means for isolating distortion components produced in signaling waves by their transmission through said devices from signaling components of the waves, said means including paths for balancing waves on the input side of the first device against signaling components of equal amplitude but opposite phase in waves from the output side of the last device, means for feeding distortion waves resulting from said balancing action through said devices, and means for compensating for phase shift which passage of waves through said stages tends to produce in the latter waves.

39. A system comprising a plurality of stages of electric space discharge devices, means for isolating distortion components produced in signaling waves by their transmission through said de-

vices from signaling components of the waves, said means including paths for balancing waves on the input side of the first device against signaling components of equal amplitude but opposite phase in waves from the output side of the last device, and means for amplifying only distortion waves resulting from said balancing action and feeding the amplified waves through said devices.

40. A signal receiving system comprising a multiplicity of amplification stages, and means coupling a portion of one amplification stage with a portion of a preceding amplification stage for impressing energy thereon in 180° phase displacement with respect to incoming signaling energy in said preceding amplification stage for regulating the amount of energy in said signal receiving system, and voltage balancing means for opposing undesired transmission of voltage from said one stage to said preceding stage through said coupling.

41. In an electrical amplifying system, a thermionic vacuum tube, an input impedance for said tube, an output transformer for said tube, a second thermionic tube of smaller capacity than said first tube, an input transformer for said second tube, means for impressing on both of said tubes certain proportions of a signal to be amplified, means for impressing on a common output circuit the outputs of both of said tubes, and means for impressing on the smaller tube a certain proportion of the output energy of said first tube.

42. In an electrical amplifying system, a plurality of electrical amplifiers, means for impressing upon said amplifiers certain portions of a signal to be amplified, means for combining the output of said amplifiers in a common output circuit, means for impressing on the input of one of said amplifiers a portion of the output of another of said amplifiers, means for reversing the phase of the amplified signal currents, and means for reversing the phase of the distortion components in said amplified signal.

43. In an electrical signaling system, an amplifier, an input circuit and an output circuit therefor, an incoming line connected to said input circuit, an outgoing line connected to said output circuit, a second amplifier of smaller capacity than said first amplifier, means for coupling said second amplifier to said output circuit, means for coupling said second amplifier to said incoming line, and means for coupling the output circuit of said first amplifier to the input circuit of said second amplifier for impressing on said second amplifier distortion currents produced in said first amplifier, the signal currents being neutralized in the input circuit of said second amplifier.

44. A wave translating system comprising a main amplifying device producing wanted and unwanted waves, an auxiliary amplifying device for amplifying said unwanted waves, means for connecting the output of said main amplifying device to the input of said auxiliary amplifying device, means for balancing out said wanted waves at the input of said auxiliary amplifying device, said last-mentioned means comprising means connecting the input of said main amplifying device to the input of said auxiliary amplifying device, and means comprising a connection from the output of said auxiliary amplifying device to said main amplifying device for causing said unwanted waves amplified by said auxiliary amplifying device to be transmitted from

the output of said auxiliary amplifying device to the output of said main amplifying device and the input of said auxiliary amplifying device.

45. In combination, an amplifying space discharge device having cathode, anode, a control grid and a second grid, an input source connected to cathode and control grid, an outgoing circuit connected to the cathode and anode, and a distortion-compensating feedback connection from a point on the output side of said device to said second grid feeding to said second grid waves of phase and amplitude to reduce distortion in the amplifier below its value for zero feedback.

46. In combination, an amplifying circuit comprising a space discharge device having a cathode, an anode, a control grid and a second grid, means to bias the control grid and the second grid with respect to the cathode, means to apply signaling voltages to the control grid, said amplifying circuit tending to produce distortion components in its output, and feedback means to reduce said distortion products below their value for zero feedback comprising a connection feeding a portion of the output waves to said second grid.

47. In an amplifying system, an amplifier having an input and an output and serving to amplify waves from said input into said output, said amplifier tending to produce output wave components other than those representing the amplified input waves, and means for reducing the magnitude of such other components comprising a first circuit deriving a portion of the input waves from said input circuit, a second circuit deriving a portion of the output waves, including amplified input waves and said other wave components, from said output circuit, a third circuit, said first and second circuits being associated with respect to each other and to said third circuit to set up in the third circuit waves representing substantially exclusively said other wave components, and means connecting said third circuit to said amplifier system at a point such that a portion of the amplifier serving to amplify said input waves is interposed between the third circuit and the second circuit, whereby said other wave components are negatively regenerated around said portion of the amplifier and said second and third circuits.

48. A system according to claim 47 in which said third circuit contains amplifying means for amplifying said other wave components substantially exclusively of the other mentioned waves.

49. In an amplifying system, an amplifier having an input and an output and serving to amplify signal variations impressed on said input, said amplifier tending to distort the wave form of the signal variations, the distortion containing frequency components different from the signal

variations, a circuit branch from said input for transmitting waves therefrom substantially without distortion, a circuit deriving from the amplifier output waves corresponding to the signal variations together with the distortion products thereof, said two circuits being differentially related such that the waves transmitted through them neutralize each other substantially except for the distortion products, and means for deriving the distortion products from said two last-mentioned circuits and for impressing them on an input portion of said amplifier in such phase as to reduce the distortion products appearing in the output of said amplifying system.

50. In an amplifying system, an amplifier having an input and an output and serving to amplify waves from said input into said output, said amplifier tending to produce output wave components other than those representing the amplified input waves, a circuit branched from said input for transmitting waves from said input substantially without distortion, a circuit deriving a portion of the output waves, said two circuits being differentially related such that the waves transmitted through them neutralize each other substantially except for the said wave components other than those representing the amplified input waves, and means for impressing said wave components on an input portion of said amplifier in proper phase to increase the ratio of the amplified input waves in the output circuit to the output wave components other than those representing the amplified input waves.

51. A wave translating apparatus, having an input and an output, means to apply waves to said input for transmission through said apparatus, said waves producing modulation in said apparatus, means for balancing waves from said output against the applied waves to isolate modulation products, means for amplifying the isolated modulation products separately from the other waves, and means for impressing the amplified modulation products on the input of said apparatus in such manner as to reduce the magnitude of the modulation in said output.

52. A wave translating apparatus, having an input and an output, means to apply waves to said input for transmission through said apparatus, said waves producing modulation in said apparatus, means for balancing waves from said output against the applied waves to isolate modulation products, means for amplifying the isolated modulation products separately from the other waves, and means for impressing the amplified modulation products on the input of said apparatus in such manner as to alter the magnitude of the isolated modulation products.

HAROLD S. BLACK.