Oct. 28, 1947.

C. G. SERIGHT

2,429,775

AMPLIFIER SYSTEM

Filed June 22, 1944

2 Sheets-Sheet 1

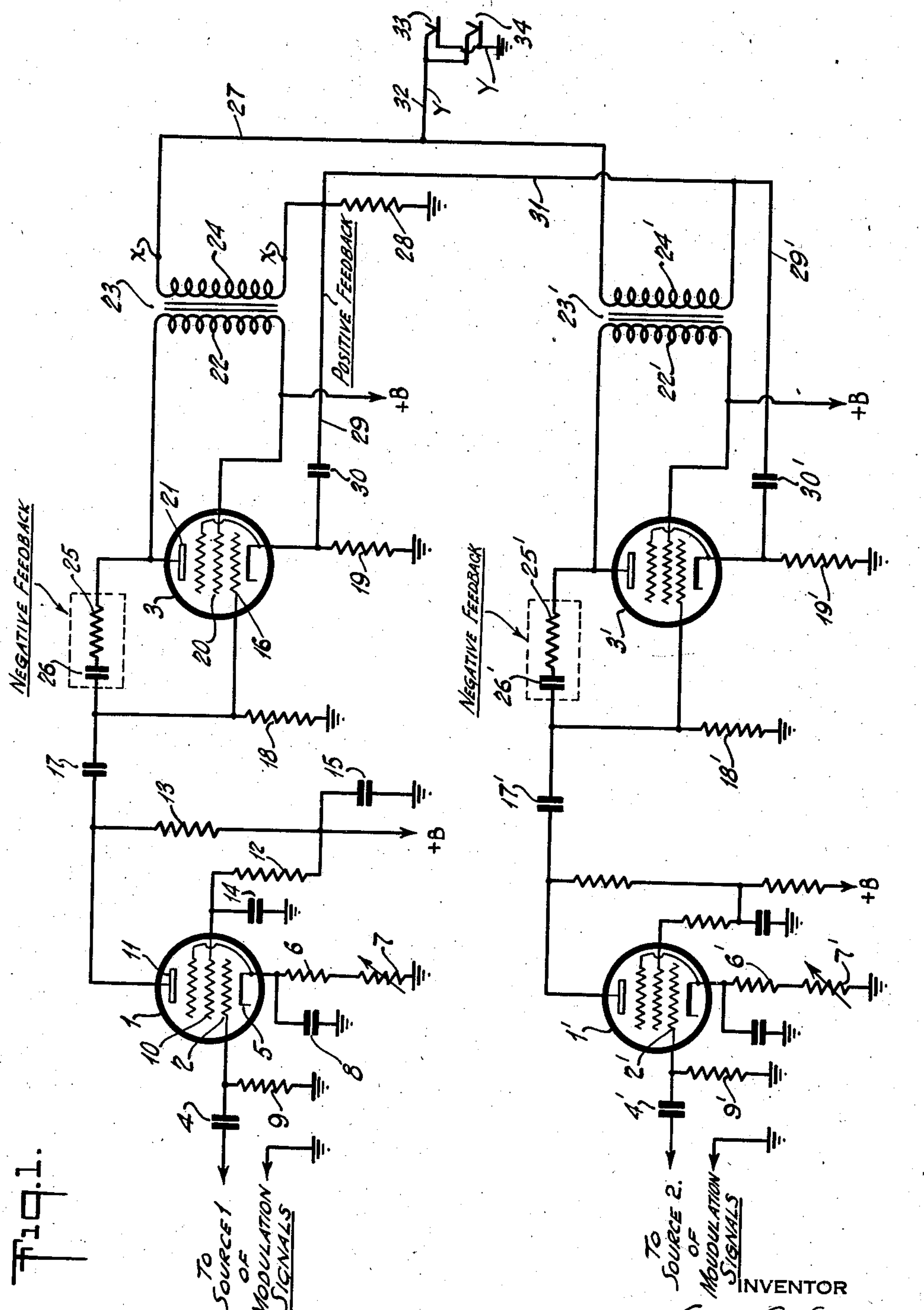

Fig. 1.

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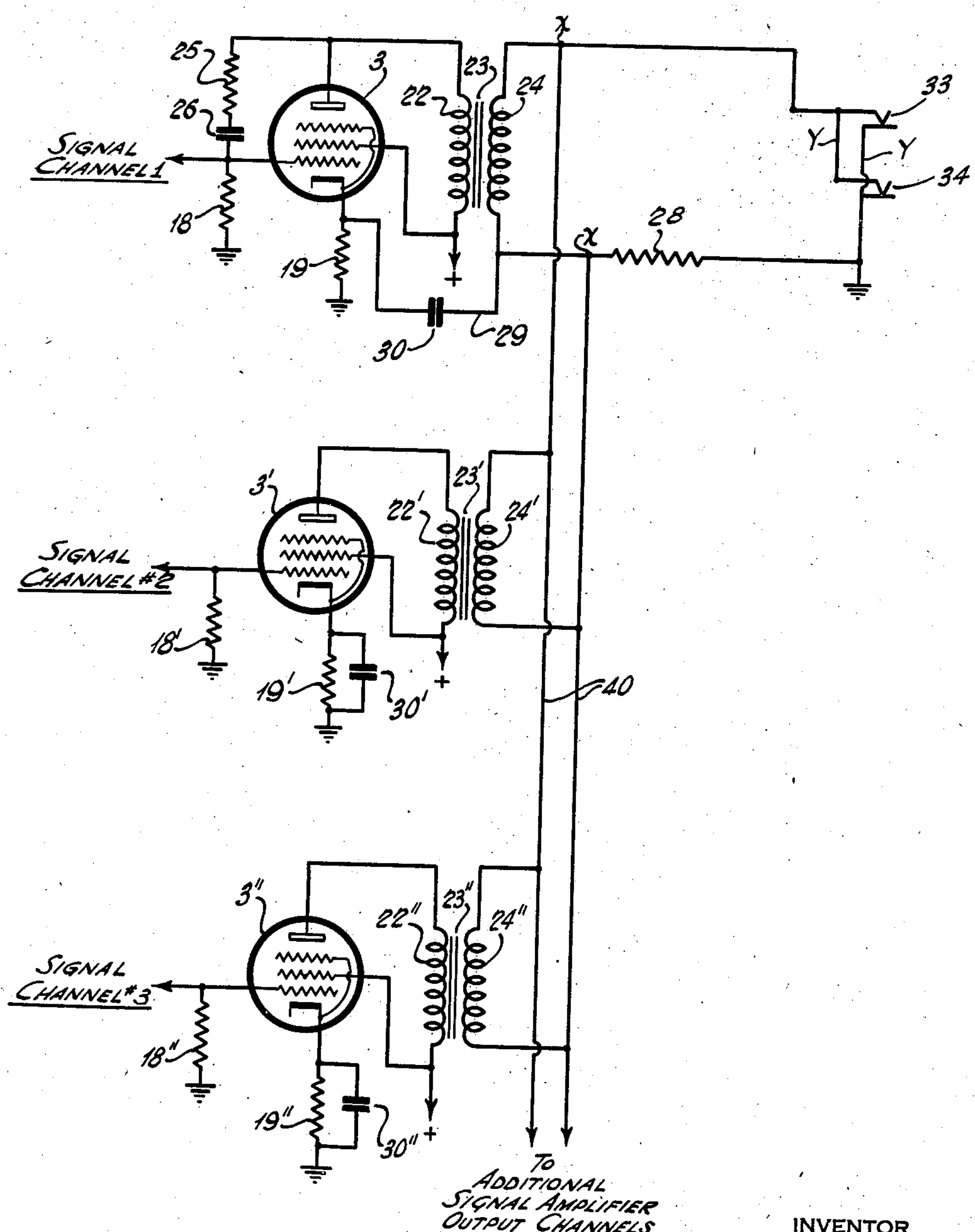
2 Sheets-Sheet 2

Fig. 2.



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UNITED STATES PATENT OFFICE

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AMPLIFIER SYSTEM

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11 Claims. (Cl. 179—171)

1

My present invention relates to amplifier systems, and more particularly to a stabilized amplifier system having a plurality of reproducer output elements.

One of the important objects of my invention is to provide a plurality of signal transmission channels with a common output circuit subject to load impedance variation; there being employed a novel and effective method of minimizing changes in signal output level due to said impedance variation.

Another important object of my invention is to provide a method of stabilizing the audio output level at the common output circuit of paralleled audio channels of respective receivers so that one or more reproducer units can be connected to the common output circuit to listen to the output of one or more of the audio channels.

Still another object of my invention is to provide in an amplifier system a method of, and means for, utilizing negative and positive feedback of signal voltage so related as to produce a stabilized signal output level regardless of load impedance variation.

Another object of my invention is to provide a plurality of signal transmission channels, wherein each channel is adapted to be fed by signals of different character, each channel having a degenerative feedback path individual to it, and a common positive feedback path being provided for all the channels to cooperate with the individual degenerative paths to provide a stabilized signal output level.

Other features of my invention will best be understood by reference to the following description, taken in connection with the drawing, in which I have indicated diagrammatically two circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows one embodiment of the invention,

Fig. 2 shows a modification.

Referring now to Fig. 1 of the accompanying drawing, wherein there is shown only so much of a pair of paralleled signal transmission channels as is essential to a proper understanding of my invention, it is to be understood that the two channels are of substantially similar construction. However, each channel transmits signals of different character. The amplifiers 1 and 1′ of the respective transmission channels may have the signal input grids 2 and 2′ thereof connected to any desired sources of signals. The signal sources are not shown, since they may be of any

2

desired construction. For example, the channels may be fed from the respective detector loads of separate radio receivers operating in widely different frequency bands. Merely as a specific illustration of such use, one receiver could be operative in the 0.19 to 2 megacycle (mc.) band, while the other is operative in the 2 to 18 mc. range. In such case the demodulator of one receiver might feed speech signals to one of the grids 2, while the demodulator of the other receiver would feed impulse or directional signals to the second channel. Again, the sources feeding grids 2 and 2′ could be separate microphones functioning intermittently or concurrently. They could readily be electrical pickups of record reproducing equipment.

Assuming, now, that separate receiving systems feed the detected outputs, or modulation signals, thereof respectively to said transmission channels, there will now be explained the specific construction of the channel component elements. Since the elements of the pair of channels are similar, reference will be made to the upper one of them. The lower channel components are denoted by the same numerals, except that a prime designation distinguishes these reference numerals from the corresponding numerals of the specifically described channel. Of course, as many signal channels as is desired may be fed from each demodulator, or as many separate receivers as is desired may be employed to feed a corresponding number of transmission channels having paralleled output circuits.

Amplifier tubes 1 and 3, while shown as pentodes, may be of any desired and suitable types. The signal grid 2 of tube 1 is coupled by condenser 4 to its modulation or other low frequency signal source. Cathode 5 is connected to ground by a bias resistor made up of two sections 6 and 7. Section 7 is shown as adjustable so as to provide control over the gain of the channel. Condenser 8 shunts resistor 6—7 to bypass alternating currents, and resistor 9 provides a direct current return path for grid 2 so as to apply negative bias to the grid relative to the cathode 5. The screen 10 and plate 11 of tube 1 are connected to a point of suitable positive potential +B by respective resistors 12 and 13. The screen and plate voltage supply leads are bypassed to ground for alternating currents by condensers 14 and 15 respectively.

The amplified modulation signal voltage across resistor 13 is applied to signal grid 16 of amplifier tube 3 by direct current blocking condenser 17. The grid 16 is connected by condenser 17 to the plate end of resistor 13, while resistor 18 returns grid 16 to the grounded end of cathode resistor 19. The latter supplies negative biasing voltage thereacross for grid 16. Condenser 30 is a direct current blocking condenser in the feedback path. The screen 20 and plate 21 of the amplifier tube are connected to respective ends of the primary winding 22 of output transformer 23, while the lower end of winding 22 is connected to a suitable positive potential point +B.

Negative or degenerative signal voltage feedback is provided by a path 25—26—18, of which the resistor 18 is common to the output and input circuits of amplifier tube 3. The portion of the negative feedback path which is connected between plate 21 and grid 16 is enclosed in a dotted rectangle, and comprises resistor 25 and condenser 26 connected in series. The constants of transformer 23 and of the path 25—26—18 are chosen so as to provide degeneration to the desired extent of the signals applied to grid 16.

The secondary winding 24 of output transformer 23 has the upper end thereof connected to an output lead 27, while the lower end is connected to ground through a resistor 28. The latter is unbypassed, and develops thereacross low frequency signal voltage. The connection 29, including direct current blocking condenser 30, is made from the upper end of resistor 28 to the cathode end of resistor 19. The polarity of winding 24 is so chosen that path 29—19 acts as a positive signal voltage feedback path. In other words, this feedback path contains resistor 19 which is common to the output and input circuits of tube 3, and it feeds back signal voltage in a sense or phase resulting in self-reinforcement, and opposite to that of the negative feedback path 25—26—18.

The output connection 27 is common to the high potential terminals of windings 24 and 24′ of transformers 23 and 23′. The low potential end of winding 24′ is connected by lead 31 to the ungrounded end of resistor 28. Hence, the resistor 28 is common to the output circuits of both channels, and functions to provide positive feedback voltage for both of amplifiers 3 and 3′, the latter through condenser 30′ and resistor 19′.

The output load of both channels comprises one or more signal outlets or jacks adapted to receive respective signal reproducer devices. Thus, the common connection 32 leads from connection 27 to a pair of parallel jacks 33 and 34, and the latter have a common ground return connection. Of course, as many jacks as is desired may be shunted across the common output circuit of the two channels. The reproducer devices may be headphones, as would be the case in aircraft reception where one headphone set might serve a pilot and the other set would be that of the radio operator. Each of the headphones would be plugged into respective jacks 33 and 34 in such case, or one of them could be removed.

The function of the negative feedback path 25—26—18 and positive feedback path 28—29—30—19 in each channel is to minimize changes in signal output level due to changes in the load connected to the common output circuit, and due to cross loading effects between the amplifiers. The receiving systems feeding the audio channels are operable one at a time, or simultaneously. Further, changes in the kind or number of reproducer devices plugged into the outlets or jacks affect the signal output level.

Again, rendering either transmission channel inoperative, as by turning off its filament voltage, substantially alters the load on the other circuit. My invention provides a simple method of minimizing changes in the signal output level resulting from load impedance variations regardless of the cause of such variations.

In order to visualize the functioning of my invention, consider first the effects of the feedbacks at the load terminals Y—Y. The impedance seen by the load at Y—Y can be determined by substituting a voltage for the load, and dividing this voltage by the resulting current.

Let

E_0=an alternating voltage applied at terminals Y—Y in place of the load.

E_g=the sum of the feedback voltages on grid 16.

μ=amplification factor of tube 3.

R_P=internal output resistance of tube 3.

R_F=resistance in ohms of positive feedback resistor 28.

N=ratio of output transformer 23=secondary turns÷primary turns.

A=fraction of the voltage established across R_F which is applied between cathode and grid of tube 3 in regenerative phase.

B=fraction of the voltage across the primary 22 of output transformer 23 which is applied between grid and cathode in degenerative phase.

I_0=current due to voltage E_0.

The product of the current and impedance equals the applied voltage ($E_0=I_0R_0$). The total voltage acting in the output circuit is the sum of the applied voltage and the feedback voltages, and the impedance is the sum of the feedback resistance R_F (28) and the plate resistance of the tube reflected through transformer 23:

$$E_0+\mu E_g N=I_0[R_F+R_P N^2]$$

Since, in the circuit under consideration, both positive and negative feedbacks are used, the total grid voltage is:

$$E_g=AR_FI_0+\frac{BE_s}{N}$$

wherein E_s=the voltage across secondary 24 of output transformer 23.

$$E_s=E_0-I_0R_F$$

$$E_g=AR_FI_0+\left(\frac{BE_0-BI_0R_F}{N}\right)$$

The full Ohm's law equation can now be set down:

$$E_0+\mu AR_FI_0N+(\mu BE_0-\mu BI_0R_F)=I_0[R_F+R_PN^2]$$

The assignment of polarities to the feedback voltage terms in the foregoing expression is made on the basis of their effect as they reappear in the amplifier output at X—X. These voltages are in series with E_0 in the output circuit Y—Y, X—X, R_F. If they act in concert with E_0 to increase I_0, they have the same sign as E_0. The polarity of the B term voltage (enclosed in parentheses) for the condition $R_F=0$ is the reverse, from a parallel standpoint, of the E_0 voltage, since the B voltage is degenerative. Acting in series with E_0 through X—X, R_F and Y—Y, this voltage therefore assists E_0 in production of I_0. The A term voltage is regenerative, if originated by a voltage appearing at X—X, as for example a B term voltage. The A term voltage reappearing at X—X would reinforce the originating voltage. The A term voltage is produced by I_0R_F drop in R_F. If this I_0R_F drop is produced by a voltage E_0 applied at Y—Y, the current through R_F, and consequently the polarity of the voltage established therein, is the reverse of the "normal" A voltage polarity, thus coinciding with the polarity of the B voltage appearing at X—X produced by E_0 applied at Y—Y. All the voltage terms, therefore, mutually assist in the production of I_0, hence all have the same sign.

Proceeding with the solution:

$$E_0(1+\mu B)=I_0[R_F+R_PN^2-\mu AR_FN+\mu BR_F] \quad (1)$$

$$R_0=\frac{E_0}{I_0}=\frac{R_F+R_PN^2-\mu AR_FN+\mu BR_F}{1+\mu B}$$

It is to be remembered that in the foregoing expression, both the A and the B terms are positive quantities. Losses in the output transformer **23** are neglected as they can be made negligible by suitable design.

It can be seen from (1) that increasing either the positive feedback, as by increasing the value of R_F (**28**), or increasing the negative feedback, as by decreasing resistor **25**, will result in a reduction of impedance R_0 presented by the circuit to the load at Y—Y. The value of R_0 can be made positive, zero, or negative, by suitable choice of values of resistor **28**, A and B. A lowered value of R_0, obtainable by the use of feedback, is desirable for minimizing output variations due to load changes. Thus, if it is desired to maintain the total output into load jacks **33—34** constant as the impedance of this load is changed, values of resistor **28**, A, and B are selected which result in an R_0 value approximating the average value of the load.

If it is desired to maintain the output per element of load constant as the number of similar load elements is varied, values of **28**, A, and B are chosen which result in an R_0 value approaching zero. The exact circuit constants necessary to affect the value of R_0 in the desired manner can either be determined by mathematical procedure of a more rigorous nature than that indicated herein, or by experimental procedure.

The use of feedback to obtain desirable loading conditions in a single amplifier, as described above, is well known. My invention consists in arranging the feedback circuits to enable a further desirable object to be obtained, namely, to permit operation of two or more amplifiers with their outputs paralleled into a common load without objectionable cross-loading between the amplifiers themselves. This I have done by providing a circuit such that the impedance presented by each amplifier to the other is not altered as a result of the feedback employed in each, when the load plugged into jacks **33—34** has a selected value.

Consider a voltage applied between points X—X, as by means of connections to output winding **24'** of another amplifier. The impedance seen by this voltage consists of two components in parallel. One branch consists of the load plugged into jacks **33—34**, plus resistance **28**. The other branch consists of the internal output impedance of the tube **3**, as modified by the ratio of transformer **23**. When pentode tubes are used, this latter component is made several times the load resistance by suitable adjustment of the transformer ratio in order to obtain maximum undistorted output from the amplifier. Thus, when no feedback is employed two pentode amplifiers paralleled as at X—X do not load each other greatly, but work efficiently into the load

resistance. In my circuit the same results are obtained while the advantages of feedback are simultaneously obtained, as set out above. Referring again to point X—X in the circuit, and assuming positive feedback through **28**, **29**, **30**, **19** equal to the negative feedback through **25—26—18** for a particular value of load impedance, it is apparent that since these feedback effects are equal and opposite at X—X, the current through the load and also through transformer winding **24** will be the same as though no feedback to tube **3** were employed. By making the positive feedback exceed the negative feedback, the impedance seen by the second amplifier at X—X, due to the connections to **24**, can be increased over the value which would be obtained with no feedback. This condition might be found desirable under some conditions; for example, if tubes having low internal output impedance were to be used in the amplifier.

The impedance presented by the circuit to another amplifier paralleled at X—X varies with the load resistance plugged into jacks **33—34** in accordance with the following relation, derived in a manner similar to Equation 1.

$$R_s=\frac{R_PN^2}{1-\frac{\mu AR_FN}{R_F+R_L}+\mu B} \quad (2)$$

In the aforesaid Equation 2 R_s=resistance presented by the circuit at X—X, with feedback, but exclusive of the load branch.

R_L=load resistance plugged into jacks **33—34**. Other notations are the same as given for Equation 1, and the A and B terms again are to be considered positive quantities.

Equation 2 shows that for a selected value of R_L, if the positive and negative feedbacks are made equal, by a proper choice of values for A, R_F and B, the circuit impedance at X—X is equal to R_PN^2, which is the value obtained with no feedback. The manner in which the impedance at X—X decreases with an increasing value of R_L can also be found by Equation 2. A similar representation can be made for the impedance presented by the second amplifier to the first or by a third amplifier to the first and second.

The desired characteristics for cross loading effects between amplifiers are obtained in my circuit by using a positive feedback element which is common to all the amplifiers. This element is numbered **28** in the accompanying drawing, and can either be a resistance, as shown, or a reactive or complex impedance if a frequency discrimination is to be imparted to the feedback action. The positive feedback voltage is shown applied in the cathode circuit, but it might equally well be applied in the grid circuit, or the plate circuit of the preceding tube, or at some previous point in the circuit.

The impedance presented to the load at Y—Y by two or more similar amplifiers with their outputs paralleled at X—X can be found by dividing R_P everywhere it appears in Equation 1 by the number of amplifiers in parallel. Thus, although the input to the load from one of the amplifiers can be rendered largely insensible to the effect of adding a second amplifier in parallel, as set out above, this condition actually obtains for only one value of load impedance. For abnormally high load impedance, the output may be substantially decreased as the second (or third) amplifier is connected in parallel, as can be determined from Equation 2. For abnormally low load impedance, the reverse effect would be obtained. Nevertheless, the circuit constants can be so adjusted as to maintain a more stabilized output condition than has heretofore been obtainable with circuits not incorporating the common feedback element represented by **28**, and the circuit is particularly useful in cases where one or more such amplifiers may be used individually or simultaneously with a common load.

Merely by way of specific illustration the following list of constants is given for the system of Fig. 1:

R_{28}=68 ohms
R_{25}=2.2 megohms
R_{19}=1000 ohms
R_{6}=1500 ohms
R_{7}=1000 ohms
C_{26}=680 micromicrofarads
C_{30}=20 microfarads
C_{17}=0.01 microfarad
Transformer (**23**) impedance ratio=40:1

Summing up, then, one aspect of the operation of the system of Fig. 1, and assuming the load at points **33**, **34** to be in the form of headphones, and for purposes of the present point considering only one of the amplifiers, we may assume first that the load consists of one headphone only. If, then, we add a second headphone in parallel with the first, we cut the ohmic resistance of the load in half so that, looking upon secondary **24** as a source of alternating current energy, the voltage drop across the load is reduced and the voltage drop across positive feedback resistor **28** is increased. We thereby attain reduced negative feedback through **25**, **26**, **18**, and increased positive feedback across resistor **28**, when energy is fed in parallel to an increased number of headphones. Of course, if the headphones were connected in series instead of in parallel, the action would be reversed in that the negative feedback would be increased and the positive feedback would be decreased as the number of series-connected headsets was increased. Substituting a positive parallel feedback for the negative parallel feedback, and a negative series feedback for the positive series feedback described elsewhere herein, would likewise reverse the action obtained.

Another circuit arrangement which I have devised is particularly suitable when the number of amplifiers which may be in operation in parallel is variable, and when the load impedance is variable, and it is desired to maintain either a constant total output per amplifier into the load, or a constant output per amplifier per element of load into a load consisting of a variable number of elements. Such a circuit is shown in Fig. 2, wherein one (or more) tube (or tubes) provides the common positive and negative feedbacks, while additional tubes not employing feedback within themselves are employed for additional amplifiers. With this modified arrangement, the tube incorporating the two feedback paths is always left in the circuit regardless of any other combination of outputs, and may serve as one of the amplifiers and also as a variable resistor which is governed by the load impedance, or may fulfill the latter function only. The essential features to be noted about this circuit are:

(A) The impedance presented by the output circuit of each of the amplifiers not employing feedback to the other amplifier output circuit, is equal to $R_P N^2$, and this is also the impedance presented by the feedback tube **3** to the other amplifiers when the load has a selected value for which the positive and negative feedback effects are made equivalent. A typical output pentode has an internal output resistance of 70,000 ohms, and a rated load resistance of 7000 ohms. Thus, several such tubes can be operated in parallel without serious loss in energy available to the load from any of the tubes.

(B) The impedance presented to the other amplifiers by the tube incorporating the feedback is that given by the aforesaid Equation 2. This impedance can be seen to vary in an inverse manner as the load impedance is varied. The feedback tube **3**, therefore, alters its impedance in a manner tending to use up the excess energy from all sources when the load impedance is increased, and conversely tends to apply additional energy to the load when the load impedance is reduced regardless of the original source of the signal or signals.

A preliminary set of values for A, R_F, and B can be arrived at by substituting actual circuit constants in Equations 1 and 2. Final circuit values are more easily determined by laboratory experimental procedure.

The modification shown in Fig. 2 follows the numbering of Fig. 1. The feedback amplifier tube **3** is provided with the positive feedback element **28** and the negative feedback path **25**—**26**. It will be seen that the electrical circuits associated directly with tube **3** are exactly the same as those in Fig. 1. Tube **3'** is provided with the same circuits as in Fig. 1, save that the degenerative path **25'**—**26'** is omitted, and condenser **30'** by-passes cathode resistor **19'** to ground. The third amplifier **3''** is provided with circuits exactly similar to those of tube **3'**. Therefore, the same numerals are used for the circuits of tube **3''**, except that double prime designations are utilized in the latter case. Leads **40** may connect to additional signal amplifier output channels.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention.

What I claim is:

1. In combination with at least two signal transmission channels each having input terminals adapted to be connected to a respectively different source of signals, a common output circuit for said channels, separate means for each channel providing negative signal voltage feedback, and a common positive signal voltage feedback path from said common output circuit to each of said channels.

2. In combination with at least two signal transmission channels each having input terminals adapted to be connected to a respectively different source of signals, a common output circuit for said channels, separate means for each channel providing negative signal voltage feedback, a common positive signal voltage feedback path from said common output circuit to each of said channels, and said common positive feedback path including an impedance in said common output circuit across which is developed the positive feedback voltage.

3. In combination with a pair of amplifier channels, each of said channels having input terminals upon which may be applied signals of different character, a common output circuit for said channels including a load whose impedance is adapted to vary, separate negative signal

voltage feedback means in each of said channels, an impedance in said common output circuit adapted to develop a signal voltage whose magnitude depends on the load impedance, and means for applying said last named signal voltage in regenerative phase to each of said channels thereby to overcome the effect of the variable load impedance on the signal output level at said common output circuit.

4. In combination with a plurality of audio frequency amplifiers, separate signal sources each feeding a respective one of the amplifiers, a common output circuit connected to the output terminals of all of said amplifiers, said output circuit including a load whose impedance is adapted to vary, and separate degenerative and regenerative feedback means operatively associated with at least one of said amplifiers to overcome the effect of said variable load impedance.

5. In combination with at least two audio frequency signal transmission channels each having input terminals adapted to be connected to a respectively different source of audio signals, a common audio output circuit for said channels, a plurality of reproducer outlet jacks in said output circuit, means for at least one channel providing negative signal voltage feedback, and a positive signal voltage feedback path from said common output circuit to at least said one channel.

6. In combination with at least two signal transmission channels each having input terminals adapted to be connected to a respectively different source of signals, a common output circuit for said channels, means for one channel providing negative signal voltage feedback, and a positive signal voltage feedback path from said common output circuit to said channel, and said positive feedback path including a resistive impedance in said common output circuit across which is developed the positive feedback voltage.

7. In combination with a pair of amplifier channels, each of said channels having input terminals upon which may be applied signals of different character, a common output circuit for said channels including a load whose impedance is adapted to vary, negative signal voltage feedback means in at least one of said channels, a resistive impedance in said common output circuit adapted to develop a signal voltage whose magnitude depends on the load impedance, and means for applying said last named signal voltage in regenerative phase to said channel thereby to overcome the effect of the variable load impedance on the signal output level at said common output circuit.

8. In combination with at least three signal transmission channels each having input terminals adapted to be connected to a respectively different source of signals, a common output circuit for said channels, means in one channel providing negative signal voltage feedback, and a positive signal voltage feedback path from said common output circuit to said one channel.

9. In combination with at least three signal transmission channels each having input terminals adapted to be connected to a respectively different source of signals, a common output circuit for said channels, means in one channel providing negative signal voltage feedback, a positive signal voltage feedback path from said common output circuit to said one channel, and said positive feedback path including an impedance in said common output circuit across which is developed the positive feedback voltage.

10. In combination with at least three amplifier channels, each of said channels having input terminals upon which may be applied signals of different character, a common output circuit for said channels including a load whose impedance is adapted to vary, negative signal voltage feedback means in one of said channels, a resistor in said common output circuit adapted to develop a signal voltage whose magnitude depends on the load impedance, and means for applying said last named signal voltage in regenerative phase to said one channel thereby to overcome the effect of the variable load impedance on the signal output level at said common output circuit.

11. In combination with three audio frequency signal transmission channels each having input terminals adapted to be connected to a respectively different source of audio signals, a common audio output circuit for all of said channels, a plurality of reproducer outlet jacks in said output circuit, means for one channel providing negative signal voltage feedback, and a positive signal voltage feedback path from said common output circuit to the one channel.

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