Dec. 6, 1938. W. SOLLER 2,138,891

ELECTRON TUBE AMPLIFICATION SYSTEM

Filed Sept. 25, 1934

FIG. 1

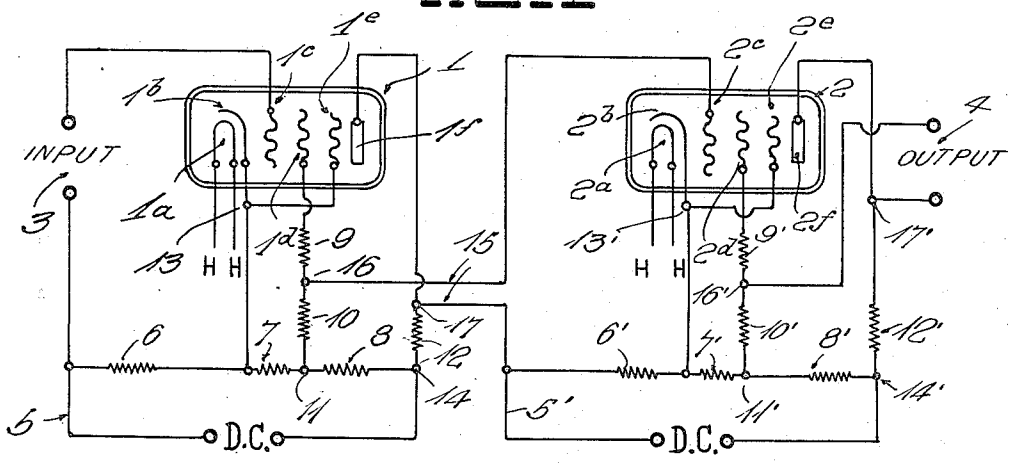


FIG. 2

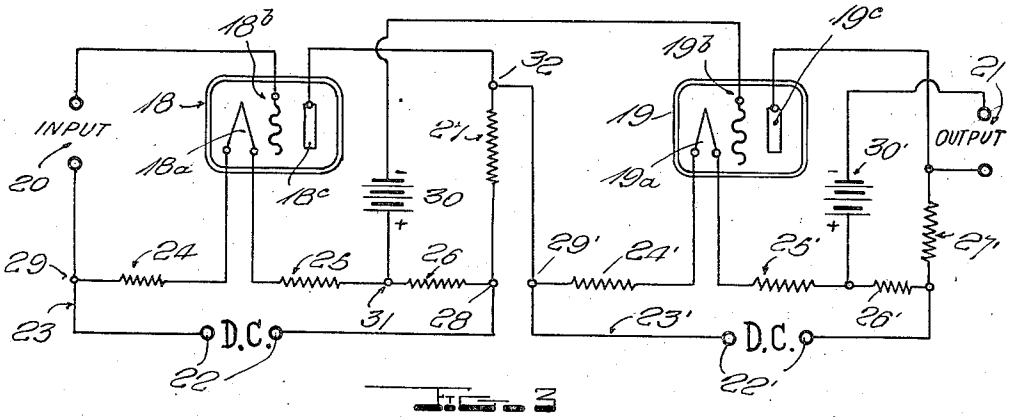
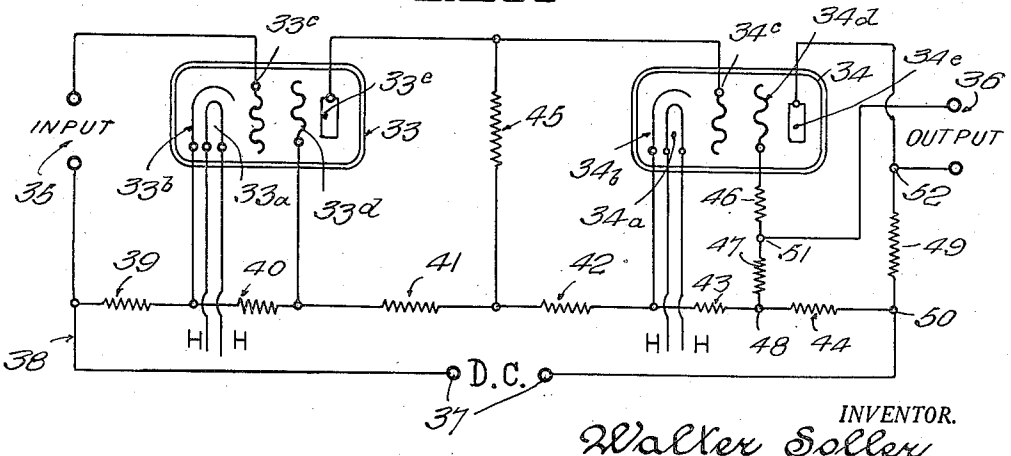


FIG. 3



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ELECTRON TUBE AMPLIFICATION SYSTEM

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Application September 25, 1934, Serial No. 745,460

2 Claims. (Cl. 179—171)

My invention relates broadly to electron tube amplification systems and more particularly to a balanced amplification system highly stable in its operation.

This application is a continuation in part of my application Serial Number 688,833 filed September 9, 1933 and entitled Balanced electron tube circuits.

One of the objects of my invention is to provide an electron tube amplification system employing multiple electrode electron tubes in which the electrodes are interconnected by balanced circuits for insuring stabilized operation of the amplification system.

Another object of my invention is to provide a balanced electron tube amplification system employing pentode electron tubes in which all stages are balanced for insuring stabilized operation of the amplification system.

Another object of my invention is to provide a circuit arrangement for insuring balanced operation of a resistance coupled electron tube amplification system for effecting maximum amplification per stage without interference from parasitic oscillations.

Still another object of my invention is to provide a resistance coupled electron tube amplification system in which opposing potentials are introduced in selected portions of the resistance coupled amplifier circuit for preventing oscillation while allowing maximum amplification.

Another object of my invention is to provide an electron tube amplification system having circuits interconnecting the electrodes of the electron tubes including a resistor carrying current of one electron tube element, the potential drop across which is balanced by the sum of a drop of potential across a resistor carrying part or all of the current of the total supply power, and another voltage either produced by the drop in potential across a resistor carrying the current of any other element of the same tube or any separately introduced voltage of any kind.

A further object of my invention is to provide an electron tube amplification system in which balanced operation is obtained by balancing the potential drops in elements connected with the electrodes of the electron tubes to a substantially balanced condition and then introducing an additional voltage for completely balancing the operation of the amplification system.

A still further object of my invention is to provide a pentode amplification system in which balancing of the entire amplifier may be effected in the final amplification stage.

Other and further objects of my invention reside in the method and circuit arrangement for balancing the operation of electron tube systems, as set forth more fully in the specification hereinafter following by reference to the accompanying drawing, in which Figure 1 is a circuit arrangement of a pentode amplifier system employing my invention; Figure 2 illustrates my invention as applied to a three element electron tube amplifier system and Figure 3 shows the application of my invention to a tetrode circuit wherein balancing is obtained in the final amplification stage.

Referring to the drawing in detail, Figure 1 illustrates my invention as applied to a balanced amplifier employing pentode electron tubes. Any of the many multiple plate and grid tubes may be used in circuits similar to the circuit shown in Figure 1. In the arrangement shown in Figure 1 two stages of amplification have been illustrated for the purpose of explaining my invention but it will be understood that any number of amplification stages may be employed.

The pentodes are indicated by reference characters 1 and 2. Pentode 1 includes heater element 1*a*, cathode 1*b*, grid electrodes 1*c*, 1*d* and 1*e* and plate electrode 1*f*. Heater element 1*a* is energized from alternating current derived from a suitable power pack connected to terminals HH. Similarly, pentode 2 includes heater element 2*a*, cathode 2*b*, grid electrodes 2*c*, 2*d* and 2*e* and plate electrode 2*f*. The input circuit to the amplifier system is represented at 3; the output from the amplifier system is shown at 4. The power supply for each of the pentodes is secured by means of a series circuit adapted to be connected to the filter system of a power rectifier when the tubes are operated from an alternating current source, or to the filter adapted for connection to a direct current line circuit, or to a direct current generator or a battery system.

The power supply circuit for each of the pentodes comprises a series path indicated generally at 5 containing resistors 6, 7 and 8. These resistors are selected in value to produce the desired potential drop for supplying the required biasing potential to control grid 1*c*, the desired potential to grid 1*d*, the potential for grid 1*e* and also the required potential for anode 1*f*. Grid 1*e* connects with cathode 1*b* at point 13, which is in turn connected to a point intermediate resistors 6 and 7 in the series path 5.

In addition to the resistors 6, 7 and 8 in the series circuit I provide separate potential determining resistors 9 and 10, disposed in series be-

tween the point 11 intermediate resistors 7 and 8 and the grid 1d. Also I provide a resistor 12 connected at potential point 14 in the series path 5 for determining the potential supplied to anode 1f. The resistances are selected in such proportions that accurate balanced operation of the amplifier circuit is obtained. The succeeding pentode 2 has the input circuit thereof connected with the output of pentode 1 through connections shown at 15. The connection from control grid 2c is made at a point 16 intermediate resistors 9 and 10 in circuit with grid 1d. The connection to the cathode 2b is taken at point 17 in the output circuit of pentode 1 adjacent resistor 12 and adjacent the connection of anode 1f thereto.

The resistance network and the connections to the electrodes in pentode 1, as above described, may be considered as a balanced bridge arrangement in which: resistance 8 constitutes one leg; resistance 12, a second leg; the internal resistance between cathode 1b and anode 1f of the tube, the third leg; and resistance 7, the fourth leg. This fourth leg is modified to include the internal resistance between the cathode 1b and the grid 1d of the tube 1 and resistance elements 9 and 10 connected in series, the series circuit being connected in parallel with the resistance 7. The source of potential for the bridge is connected at point 14 between resistances 8 and 12 and to the cathode 1b. The output is taken from the opposite terminals of the bridge, viz., 16 and 17. The modification of the fourth leg of the bridge which includes resistance 10 permits the resistance 10 to be included also in the output circuit. The potential drop across resistance 10, or some equivalent voltage, is a necessary factor in the balancing of the bridge circuit.

The condition of balance of the bridge is the condition of zero voltage across the output terminals. Consider the voltage of cell 30 or the potential drop across resistance 10 as E, the resistances 12 and 8 as R_1 and R_0, respectively, and the currents in R_1 and R_0 as I_1 and I_0, respectively. The factors affecting the balance of the bridge are the currents I_0 and I_1. These currents are each dependent on a common factor, which is the source of potential of the system, and the effects thereof may be made to neutralize each other for any variations in the potential source by properly adjusting the resistance of the circuit.

It will be appreciated that the same principles are involved in both a direct heated cathode circuit device, as shown in Fig. 2 and the indirect cathode heating system of Figs. 1 and 3 as long as all power is obtained from the same source. There is a simultaneous change in the heating of the cathode and the plate potential under conditions of changes in the common power supply. Accordingly, variation in cathode emission due to variation of power supply in the circuits of Figs. 1 and 3 will be balanced similar to the direct heated system, as illustrated in Fig. 2.

The values of the two resistances R_0 and R_1 depend upon the characteristics of the tube and circuit. The simplest way to determine this dependence is to regard the output circuit, the voltage E, and the resistances R_0 and R_1 as a Dowling zero shunt. When a current I_0 is passing through R_0 and the current I_1 through R_1, then the requirement for no current through the output circuit is:

$$R_0I_0+E=I_1R_1 \text{ or } R_1=(R_0I_0+E)/I_1. \quad (1)$$

Now for the circuit to be balanced for a change ΔI_0 in I_0 and a corresponding change ΔI_1 in I_1, the following equation must hold:

$$R_0(I_0+\Delta I_0)+E=R_1(I_1+\Delta I_1) \quad (2)$$

Substituting for R_1 from (1):

$$R_0(I_0+\Delta I_0)+E=(R_0I_0+E)(I_1+\Delta I_1)/I_1$$

$$R_0\left(I_0+\Delta I_0-I_0-\frac{I_0}{I_1}\cdot\Delta I_1\right)=E\left(1-1+\frac{\Delta I_1}{I_1}\right)$$

Cancelling and rearranging:

$$R_0(I_1\cdot\Delta I_0-I_0\cdot\Delta I_1)=+E.\Delta I_1$$

or

$$R_0=\frac{E\cdot\Delta I_1}{-I_0\cdot\Delta I_1+I_1\cdot\Delta I_0}=\frac{E}{-I_0+I_1\frac{\Delta I_0}{\Delta I_1}} \quad (3)$$

The above is the value of R_0 for balanced conditions in terms of E, I_1, I_0 and the slope of the I_1 vs. I_0 characteristics. R_1 is then determined by Equation 1.

If E is constant (E is a constant voltage cell 30 in Fig. 2 and in Figs. 1 and 3, it can be considered as a first approximation as constant, because the effect on it of a change in electron emission is counteracted by the effect on it of the change in potential drop across resistances 7 and 25 respectively caused by a simultaneous change in I_0) it is evident that the characteristics must be such that the denominator is a constant for all values of I_0 in order that R_0 can be a constant. By putting the denominator in differential form equating it to a constant and solving the differential equation, we obtain the characteristics of I_1 vs. I_0 necessary to have R_0 a constant as follows:

$$I_0-I_1(dI_0/dI_1)=k_1 \quad (4)$$

$$I_1(dI_0/dI_1)=I_0-k_1$$

$$\int\frac{dI_0}{I_0-k_1}=\int\frac{dI_1}{I_1}$$

$$\log(I_0-k_1)=\log I_1+\log k_2$$

$$\log(I_0-k_1)=\log k_2I_1$$

$$I_0=k_2I_1+k_1 \quad (5)$$

Equation 5 is the general equation of a straight line. Therefore, if the portion of the characteristics near the operating value of I_0 is straight, the circuit will balance and remain balanced.

The length of this straight portion determines the range of external fluctuations that can be balanced. This requirement is usually fulfilled for normal operating conditions. This one-tube circuit affords so simple a means of balancing external tube variations that it is as easily set up as an unbalanced circuit, will operate much more satisfactorily, and with refinements, will balance as closely as the two-tube circuit. The advantages over the two-tube circuit are: the elimination of the difficulty in balancing, of extra apparatus, and of the necessity of obtaining exactly similar tubes, which are not readily procurable.

The balancing in these circuits is accomplished by adjusting resistances R_0, R_1, and voltage E. Without voltage E, the circuit would not balance even though it appears the drop R_0, I_0 could be made to balance drop R_1, I_1. This is not possible, as can be seen, by allowing E to equal zero in the first equation after Equation 2, which will then cause R_0 to cancel out of the equation and thereby eliminate the means of adjusting for balance. To have an additional voltage E in the circuit R_0, R_1, and the output, is an essential feature of these circuits, and may be provided from a battery, a standard cell or the like, as in Fig. 2, in lieu of the voltage drop across a resistance in the preferred form shown in Figs. 1 and 3.

The actual values of the resistances R_0 and R_1 need not be calculated from Equations 3 and 1, but can be determined experimentally as follows: A suitable D. C. electric current meter is placed across the output terminals with R_0 not far from the expected correct value and R_1 is adjusted until the meter reads zero. The supply current is then increased by increasing the voltage into the supply circuit and the deflection of the meter noted. Then, with a new value of R_0 (a value which differs from the expected correct value in the opposite direction from that of the first value taken), R_1 is again adjusted for zero reading of the meter, and the deflection of the meter again noted for an increase in supply current. If the correct value of R_0 for balance is near the value which was expected, this second deflection will be in the opposite direction to the first. Values of R_0 between these two are then taken and the above procedure repeated until a value of R_0 and R_1 is found for which no deflection is produced in the meter when the supply current is changed. Every tube even of the same type and make differs enough in characteristics to require the values of R_0 and R_1 to be determined experimentally for balance against supply power changes.

The assumption that E is constant is introduced to simplify the discussion and to show the fundamental idea of balancing against changes in supply power especially in the simplified circuit of Fig. 2, and also to show how closely the other circuits are related to it. Actually, the assumption of E being constant is an unnecessary assumption and can be replaced by the assumption that the resistances **10**, **8**, and **12** remain constant which can always be accurately fulfilled.

The following discussion will show that the circuits in Figs. 1, 2, and 3 will balance, not approximately, but completely for normal operating voltages on the tube and that the conditions are not altered from those just given, **10** being any suitable constant resistance, and R_0 and R_1 determined experimentally in exactly the same way as before. Call resistance **10**, R_2; and the current through it, I_2. Then, for balance at some current I_0 with the corresponding currents I_1 and I_2, the following equation must hold:

$$R_0I_0+R_2I_2=I_1R_1 \text{ or } R_0=\frac{I_1R_1-R_2I_2}{I_0} \qquad (6)$$

Now to remain balanced when I_0 changes to $I_0+\Delta I_0$ causing I_2 to change to $I_2+\Delta I_2$ and I_1 to $I_1+\Delta I_1$, the following equation must hold also:

$$R_0(I_0+\Delta I_0)+R_2I_2+R_2\cdot\Delta I_2=R_1(I_1+\Delta I_1)$$

substituting R_0 in this, gives

$$\frac{I_1R_1-R_2I_2}{I_0}\cdot(I_0+\Delta I_0)+R_2I_2+R_2\cdot\Delta I_2=R_1(I_1+\Delta I_1)$$

Cancelling and rearranging, gives

$$R_1(I_1.\Delta I_0-I_0\cdot\Delta I_1)=R_2(I_2\cdot\Delta I_0-I_0\cdot\Delta I_2)$$

or

$$\frac{R_1}{R_2}=\frac{I_2\cdot\Delta I_0-I_0.\Delta I_1}{I_1\cdot\Delta I_0-I_0.\Delta I_1}=\frac{I_2-I_0\frac{\Delta I_2}{\Delta I_0}}{I_1-I_0\frac{\Delta I_1}{\Delta I_0}} \qquad (7)$$

This is a similar condition to that of the previous case, the denominator having exactly the same form. Here, the numerator also has exactly the same form. In order for the denominator to remain constant with change of I_0 and I_1, it was shown that the only requirement was that the I_1—I_0 characteristics must be linear in the operating region, so here in order that the numerator remains constant with change of I_0 and I_2, the I_2—I_0 characteristics must also be linear in the operating region. These two conditions are practically always met in amplifying tubes.

As it is the ratio

$$\frac{R_1}{R_2}$$

that must fit the requirement of the characteristics of the tube given by Equation 7, the resistance R_2 can be chosen arbitrarily within the operating range and R_0 and R_1 determined experimentally in exactly the same way as indicated in the simplified discussion.

If, in place of solving first for R_0 in Equation 6, R_1 is obtained as follows:

$$R_1=\frac{R_0I_0+R_2I_2}{I_1} \qquad (8)$$

and then it is eliminated in place of R_0, the second condition of balance,

$$\frac{R_2}{R_0}=\frac{I_0-I_1\frac{\Delta I_0}{\Delta I_1}}{I_2-I_1\frac{\Delta I_2}{\Delta I_1}} \qquad (9)$$

is obtained.

From this, it is seen that R_0 can just as well be chosen arbitrarily in place of R_2 and then R_2 and R_1 adjusted for the balanced condition experimentally in exactly the same way as R_0 and R_1 were. This is a more convenient method of adjusting, as during adjustment, the tube can be held closer to its operating voltages. As R_0 is arbitrary, a special case of this circuit is when $R_0=0$.

So far, it has been shown that these circuits will completely balance out changes in the supply power sources. It will be shown now that a further adjustment of the circuits in Figs. 1, 2 and 3 is possible, whereby they will balance both changes in the power source, and changes in cathode emission due not only to variations in the power supply, but to any cause, as, for example, the deterioration of the cathode or filament. It is preferable to have the grid to which resistances **9** and **10** are connected, between the cathode and the control grid for this type of balancing. Let changes in the electron emission not due to power supply variations produce changes of $\Delta'I_2$ and $\Delta'I_1$ in I_2 and I_1 respectively. For these changes, there will be no change in I_0; i. e., $\Delta I_0=0$. For balancing at currents I_0, I_1 and I_2, we have

$$R_0I_0+R_2I_2=I_1R_1 \text{ or } R_0=\frac{I_1R_1-R_2I_2}{I_0}$$

Then for balance after a change $\Delta'I_2$ and $\Delta'I_1$ when I_0 does not change,

$$R_0I_0+R_2I_2+R_2\cdot\Delta'I_2=R_1I_1+R_1\cdot\Delta'I_1 \text{ or } \frac{R_2}{R_1}=\frac{\Delta'I_2}{\Delta'I_1} \qquad (10)$$

Equations 8, 9, and 10 are the three conditions that must be fulfilled for this balance.

Let the slopes

$$\frac{\Delta I_0}{\Delta I_1}=n_0;\ \frac{\Delta I_2}{\Delta I_1}=n_2;\ \frac{\Delta'I_1}{\Delta'I_2}=n'.$$

Then by substituting these values in Equations 8, 9, and 10 and eliminating the R's we obtain

$$I_2=I_1\cdot n'-\frac{I_2-I_1n_2}{I_0-I_1n_0}$$

the condition between the currents and slopes that must be fulfilled. The circuit of Fig. 3 fullfils all the requirements of Fig. 1 in that one power supply source is used and further allows

balancing the entire cascade at the output of the final tube.

A series power supply circuit is provided for pentode 2 similar to the power supply circuit in the first pentode stage. I have indicated the series power supply circuit for pentode 2 by reference character 5'. In the series circuit 5' there are resistor elements corresponding to those located in the power supply circuit of pentode 1, that is, the resistors 6', 7' and 8'. Grid 2e connects to cathode 2b at point 13', which in turn connects to a potential point intermediate resistors 6' and 7' in series path 5'. The grid electrode 2d is maintained at a pre-determined potential through a connection which includes resistors 9' and 10', which connection is taken from point 11' intermediate resistors 7' and 8' in the power supply circuit 5'. Anode 2f is maintained at the required potential by a connection through resistor 12' to 14' in the series path 5'. The output circuit 4 connects between terminal 16' intermediate resistors 9' and 10' and terminal 17' in the output circuit of pentode 2. The resistors are selected for such value as to obtain accurate balanced operation of the pentode stages.

Referring to Figure 2 of the drawing I have shown the balanced circuit of my invention applied to a three electrode electron tube amplifier. In this arrangement the three electrode electron tubes are indicated at 18 and 19. Tube 18 includes cathode 18a, control grid 18b and anode 18c. Tube 19 includes cathode 19a, control grid 19b and anode 19c. The input circuit is shown at 20. The output circuit connects at 21. A direct current source, such as the output terminals of a filter connected with a direct current generator, the output of the power pack of a rectifier unit or a battery source is connected with terminals 22. The series circuit 23 is arranged similarly to the series circuit 5 in Figure 1, which circuit includes resistors 24, 25 and 26 connected in series through the cathode 18a.

The potential supplied to anode 18c is determined by resistor 27 connected at the point 28 in the series path 23 and adjacent the resistor 26. The desired operating potential on grid 18b is obtained by connection of the grid circuit to the point 29 in the series path 23. The succeeding three electrode tube 19 has its input circuit connected with the output circuit of three electrode tube 18 in a very special manner designed to produce the same results which are effective when using pentodes as illustrated in the circuit of Figure 1. That is to say, an additional balancing voltage is introduced into the coupling circuit between tube 19 and tube 18. This is accomplished in the circuit of Figure 2 by employing the cell 30, having its positive terminal connected to the point 31 intermediate resistors 25 and 26 in series path 23 and having its negative terminal connected to control grid 19b. This additional cell replaces the drop which is obtained in the resistors 9 and 10 of the circuit of Figure 1 and which connect with grid 1d.

In applying the equations above to the circuits in Fig. 2, the voltage of cell 30 is represented by E, and resistances 27 and 26 by R_1 and R_0, respectively.

The circuit of my invention, either in the form shown in Figure 1 or in Figure 2, provides means for balancing the power current change against the plate current change. Balancing the potential drops due to the power current change and the plate current change is not sufficient. An additional and separate voltage must be introduced into the circuit. In Figure 2 this additional voltage is introduced by means of a cell 30; in Figure 1 this additional voltage is introduced by the potential drop across resistors 9 and 10 in circuit with grid 1d. Balanced operation of the electron tube circuits is thereby assured. The input circuit of tube 19, connected as aforesaid from control grid 19b to the additional potential source 30, has its input circuit completed by the connection from point 29' to the terminal 32 intermediate the end of resistor 27 and anode 18c.

The power supply for the succeeding electron tube 19 is provided in a manner similar to the power supply for tube 18 in series path 23', connected with terminals 22', the series path containing resistors 24', 25' and 26' connected in series through cathode 19a. Resistor 24' provides a drop which is combined with the drops produced by resistors 27' and 26' and combined with the potential of source 30' to stabilize the potential on control grid 19b. Anode 19c is provided with required potential through the drop across resistor 27'. The output circuit to the next succeeding electron tube, which connects the terminals 21, is connected through the additional source of potential 30' for introducing the balancing voltage as heretofore explained.

My invention is applicable to circuits employing electron tubes of various constructions, such as screen grid tubes, pentodes and multi-electrode tubes employing a plurality of grid and plate electrodes, and according to the type of tube employed I may provide a cell to introduce the desired potential drop for balancing or I may derive the balancing potential from the drop across resistors in circuit with a grid electrode as heretofore described in connection with Figure 1. Where structural conditions permit I may combine the power supply circuits of a multiplicity of electron tubes, as shown in Figure 3.

In this arrangement tubes 33 and 34 are shown with the output circuit of one tube coupled with the input circuit of the succeeding tube and having an input circuit 35 and an output circuit 36. The power supply of direct current characteristic is connected at 37 and traverses the series path 38, which path contains resistors 39, 40, 41, 42, 43 and 44. Tube 33 includes heater element 33a, cathode 33b, grid 33c, grid 33d and plate 33e. Similarly, electron tube 34 contains heater element 34a, cathode 34b, grid 34c, grid 34d and plate 34e.

The grid bias potential for tube 33 is determined by the drop across resistor 39 which is disposed in the grid cathode circuit. The potential on grid 33d is determined by the drop across resistor 40. The anode potential for anode 33e is determined by the drop across resistors 40 and 41. The output circuit of tube 33 is coupled with the input circuit of tube 34 through resistor 45. The bias on control grid 34c is determined by the drop across resistor 42. The potential on grid 34d is derived from the drop across resistor 43. The balancing potential on grid 34d is determined by the drop across resistors 46 and 47 connected in series with tap 48 intermediate resistors 43 and 44. The potential on anode 34e is determined by resistor 49 connected with point 50 in the series power supply circuit 38. The output circuit of the amplifier at 36 connects at point 51 intermediate resistors 46 and 47 in circuit with grid 34d and the point 52 in the output circuit of tube 34. In applying the equation above to the balancing circuit in Fig. 3, the voltage drop across resistance 47 is represented by E,

and resistances 49 and 44, by R_1 and R_0, respectively.

All of the stages of the amplifier illustrated in Fig. 3 are balanced in the last stage. This is possible because a common power supply circuit is provided for all of the stages. It will be noted that in the circuits of Figs. 1 and 2 separate power supply paths are provided for each stage.

My invention is directed to any method of changing the characteristics of a tube, as for example, by placing a resistance across the tube, so that it can be balanced. My invention is not confined to electron tubes, but is applicable to any form of cathode ray tubes.

My invention contemplates any amplification system of one or more electron tubes having three or more elements in which all elements of each tube are supplied by one source of electric power and in which the drop in potential across a resistor carrying the current of one element can be balanced by the sum of a drop of potential across a resistor carrying part or all of the total supply power current and another voltage either produced by the drop in potential across a resistor carrying the current of any other element of the same tube or any separately introduced voltage of any kind.

I have described my invention in certain preferred embodiments but I desire that it be understood that modifications may be made without departing from the spirit of my invention. For example, I have mentioned the arrangement of resistors in the power supply paths. I may employ impedances in the power supply paths in lieu of resistors. Other changes may be made in the circuits of my invention and I intend no limitations upon my invention other than imposed by the scope of the appended claims.

What I claim and desire to secure by Letters Patent of the United States is as follows:

1. An amplification system comprising a multiplicity of electron tubes, each including a cathode, a control grid and an anode, a separate series circuit containing a source of potential for energizing said cathode and anode in each of said electron tubes, a connection including a resistor from one terminal of said source of potential to said anode, a connection from the series circuit connected with the succeeding electron tube to the anode of the preceding electron tube, a connection from the control grid of the succeeding electron tube to a point in the series circuit connected with the preceding electron tube thence through a resistor in said series circuit to the terminal of said source of potential connected with said anode, and a source of compensating potential included in said last mentioned connection for balancing the potential across the connections to the succeeding electron tube circuits.

2. An electron tube amplification system including a plurality of electron tube devices each having anode, cathode and grid electrodes, a source of power individual to each of said electron tube devices, circuits interconnecting the electrodes in each electron tube device and the corresponding source of power comprising a connection from one terminal of said source of power to the anode electrode, a resistance element in said connection, a series circuit including a plurality of resistance elements connected to said source of power, a connection from said cathode electrode to a point in said series circuit intermediate two of said plurality of resistance elements, output terminals, one of said output terminals connected to said anode, and a separate source of potential, the other of said output terminals connected through said separate source of potential to a point in said series circuit thence through another of said plurality of resistance elements to the terminal of said source of power connected to said anode, the potentials of said output terminals being balanced by the algebraic sum of the voltage across said separate source of potential and the potential drops across the resistance element connected between said separate source of potential and said source of power, and across the resistance element connected between said anode and said source of power, the anode output terminal of a preceding electron tube device being connected through another of the plurality of resistance elements in the series circuit connected with the succeeding electron tube device to the cathode of said succeeding electron tube device, and the other of the output terminals being connected with the grid electrode in said succeeding electron tube device.

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