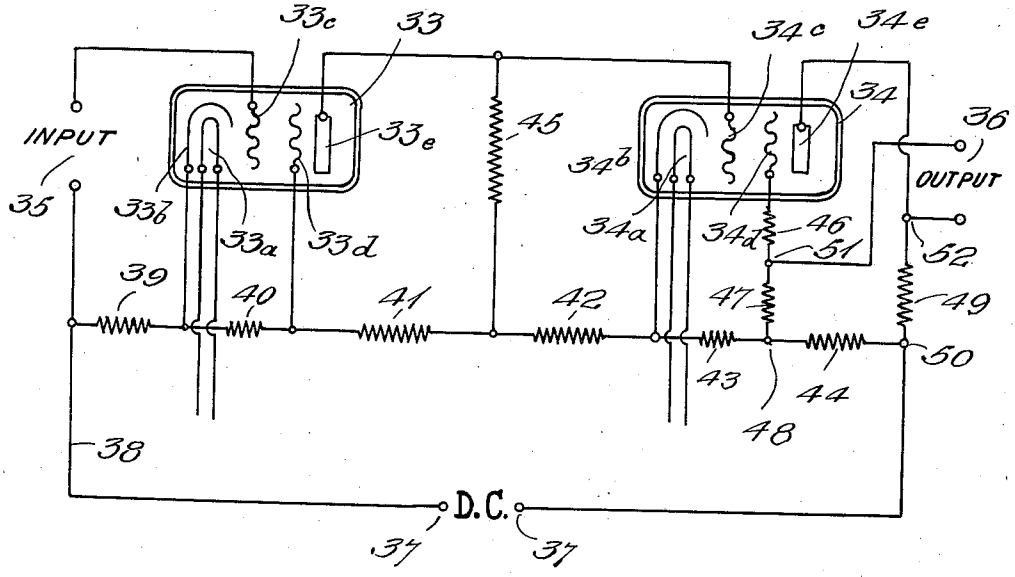
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ELECTRON TUBE AMPLIFICATION SYSTEM

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ELECTRON TUBE AMPLIFICATION SYSTEM

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4 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 division of my application Serial Number 745,460, filed September 25, 1934, for Electron tube amplification system, now patent 2,138,891, granted December 6, 1938.

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 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.

A further 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 produced by the drop in potential across a resistor carrying the current of any other element of the same tube.

A still 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 an electron tube to a substantially balanced condition and then introducing a compensating voltage for completely balancing the operation of the amplification system.

Another object of my invention is to provide a circuit arrangement for a multistage electron tube amplification system having a common power supply circuit for all of the tubes of the amplification system in which all of the stages of the amplification system are balanced in the last 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 which diagrammatically illustrates the amplification circuit of my invention.

Referring to the drawing in detail, I have illustrated my invention by a circuit arrangement for a two-stage electron tube amplifier, but I desire that it be understood that the principles of my invention are applicable to multistage amplifiers generally in which a common power supply circuit is provided for all of the electron tubes in the amplification system.

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 **33***a*, cathode **33***b*, grid **33***c*, grid **33***d* and plate **33***e*. Similarly, electron tube **34** contains heater element **34***a*, cathode **34***b*, grid **34***c*, grid **34***d* and plate **34***e*.

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 **33***d* is determined by the drop across resistor **40**. The anode potential for anode **33***e* 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 **34***c* is determined by the drop across resistor **42**. The potential on grid **34***d* is derived from the drop across resistor **43**. The balancing potential on grid **34***d* 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 **34***e* 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 **34***d* and the point **52** in the output circuit of tube **34**. All of the stages of the amplifier are balanced in the last stage. This is possible because a common power supply circuit is provided for all of the stages.

The resistance network and the connections to the electrodes in tube **34**, as above described, may be considered as a balanced bridge arrangement in which: resistance **44** constitutes one leg; resistance **49**, a second leg; the internal resistance between cathode **34***b* and anode **34***e* of the tube, the third leg; and resistance **43**, the fourth leg.

This fourth leg is modified to include the internal resistance between the cathode 34b and the grid 34d of the tube 34 and resistance elements 46 and 47 connected in series, the series circuit being connected in parallel with the resistance 43. The source of potential for the bridge is connected at point 50 between resistances 44 and 49 and to the cathode 34b. The output is taken from the opposite terminals of the bridge, viz., 51 and 52. The modification of the fourth leg of the bridge which includes resistance 47 permits the resistance 47 to be included also in the output circuit. The potential drop across resistance 47, 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 potential drop across resistance 47 as E, the resistances 49 and 44 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, and the indirect cathode heating system 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 circuit shown in my invention will be balanced similar to the direct heated system.

The values of the two resistances 44 and 49 represented by R_0 and R_1, respectively, depend upon the characteristics of the tube and circuit. The simplest way to determine this dependence is to regard the output circuit, resistance 47 which has a voltage drop designated 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 a 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):

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

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

Cancelling and rearranging:

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

or

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

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, the voltage drop across resistance 47, is constant and 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 resistance 43 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_0I_0 could be made to balance drop R_1I_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 a voltage drop E in the circuit R_0, R_1, and the output, is an essential feature of the circuit of my invention.

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 de-

flection 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. Actually, the assumption of E being constant is an unnecessary assumption and can be replaced by the assumption that the resistances **47**, **44** and **49** remain constant which can always be accurately fulfilled.

The following discussion will show that the circuit of my invention will balance not approximately, but completely for normal operating voltages on the tube and that the conditions are not altered from those just given, **47** being any suitable constant resistance, and R_0 and R_1 determine experimentally in exactly the same way as before. Call resistance **47**, 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:

$$R_0I_0+R_2I_2=I_1R_1 \text{ or } R_0=\frac{I_1R_1-R_2I_1}{I_0} \quad (6)$$

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:

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

substituting R_0 in this, gives

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

Cancelling and rearranging, gives

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

or

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

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:

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

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

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

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 balance 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 circuit of my invention is possible, whereby the circuit 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 **34***d* to which resistances **46** and **47** 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,

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

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

$$I_2=\frac{I_1}{n'}-I_0\left(\frac{I_2-I_1n_2}{I_0-I_1n_0}\right)$$

the condition between the currents and slopes that must be fulfilled.

The circuit of my invention embraces 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 also 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 a certain pre-

ferred embodiment 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 as new and desire to secure by Letters Patent of the United States is as follows:

1. A multistage electron tube amplification system including a plurality of electron tube devices, anode, cathode and grid electrodes in each of said electron tube devices, a source of power common to said plurality of electron tube devices, and a balanced output circuit connected with the electron tube device in the last stage of said amplification system comprising a connection from one terminal of said source of power to the anode in said last stage electron tube device, a resistance element in said connection, a series circuit including a plurality of resistance elements connected to said source of power, a connection from the cathode in said last stage electron tube device to a point in said series circuit intermediate two of said plurality of resistors, a grid electrode in said last stage electron tube device connected 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, a separate resistance element in said connection to said grid, and output terminals connected to said anode and said separate resistance element, the potentials of said output terminals being balanced by the algebraic sum of the potential drops across the said resistance elements connected between said anode and said source of power and between said grid electrode and said source of power.

2. A multistage electron tube amplification system including a plurality of electron tube devices, anode, cathode and grid electrodes in each of said electron tube devices, a source of power common to said plurality of electron tube devices, and a balanced output circuit connected with the electron tube device in the last stage of said amplification system comprising a connection from one terminal of said source of power to the anode in said last stage electron tube device, an impedance element in said connection, a series circuit including a plurality of impedance elements connected to said source of power, a connection from the cathode in said last stage electron tube device to a point in said series circuit intermediate two of said plurality of impedances, a grid electrode in said last stage electron tube device connected to a point in said series circuit thence through another of said plurality of impedance elements to the terminal of said source of power connected to said anode, a separate impedance element in said connection to said grid, and output terminals connected to said anode and said separate impedance element, the potentials of said output terminals being balanced by the algebraic sum of the potential drops across the said impedance elements connected between said anode and said source of power and between said grid electrode and said source of power.

3. A multistage electron tube amplification system including a plurality of electron tube devices, anode, cathode and grid electrodes in each of said electron tube devices, a source of power common to said plurality of electron tube devices, and a balanced output circuit connected with the electron tube device in the last stage of said amplification system comprising a connection from one terminal of said source of power to the anode in said last stage electron tube device, an impedance element in said connection, a series circuit including a plurality of impedance elements connected to said source of power, a connection from the cathode of the electron tube device in the last stage of said electron tube amplification system to a point in series circuit intermediate two of said plurality of impedance elements, a grid electrode in the electron tube in the last stage of said amplification system connected to a point in said series circuit, thence through another of said plurality of impedance elements to the terminal of said source of power connected to said anode, a separate impedance element in said connection to said grid, output terminals connected to said anode and said separate impedance element, the potentials of said output terminals being balanced by the algebraic sum of the potential drops across the said impedance elements connected between said anode and said source of power and between said grid electrode and said source of power, and a resistance element constituting coupling means between the output circuit of one electron tube and the input circuit of said last mentioned electron tube.

4. A multistage electron tube amplification system including a plurality of electron tube devices, anode, cathode and grid electrodes in each of said electron tube devices, a source of power common to said plurality of electron tube devices, and a balanced output circuit connected with the electron tube device in the last stage of said amplification system comprising a connection from one terminal of said source of power to the anode in said last stage electron tube device, an impedance element in said connection, a series circuit including a plurality of impedance elements connected to said source of power, a connection from the cathode of the electron tube device in the last stage of said electron tube amplification system to a point in series circuit intermediate two of said plurality of impedance elements, a grid electrode in the electron tube in the last stage of said amplification system connected to a point in said series circuit, thence through another of said plurality of impedance elements to the terminal of said source of power connected to said anode, a separate impedance element in said connection to said grid, output terminals connected to said anode and said separate impedance element, the potentials of said output terminals being balanced by the algebraic sum of the potential drops across the said impedance elements connected between said anode and said source of power and between said grid electrode and said source of power, and an impedance element constituting coupling means between the output circuit of one electron tube and and the input circuit of said last mentioned electron tube.

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