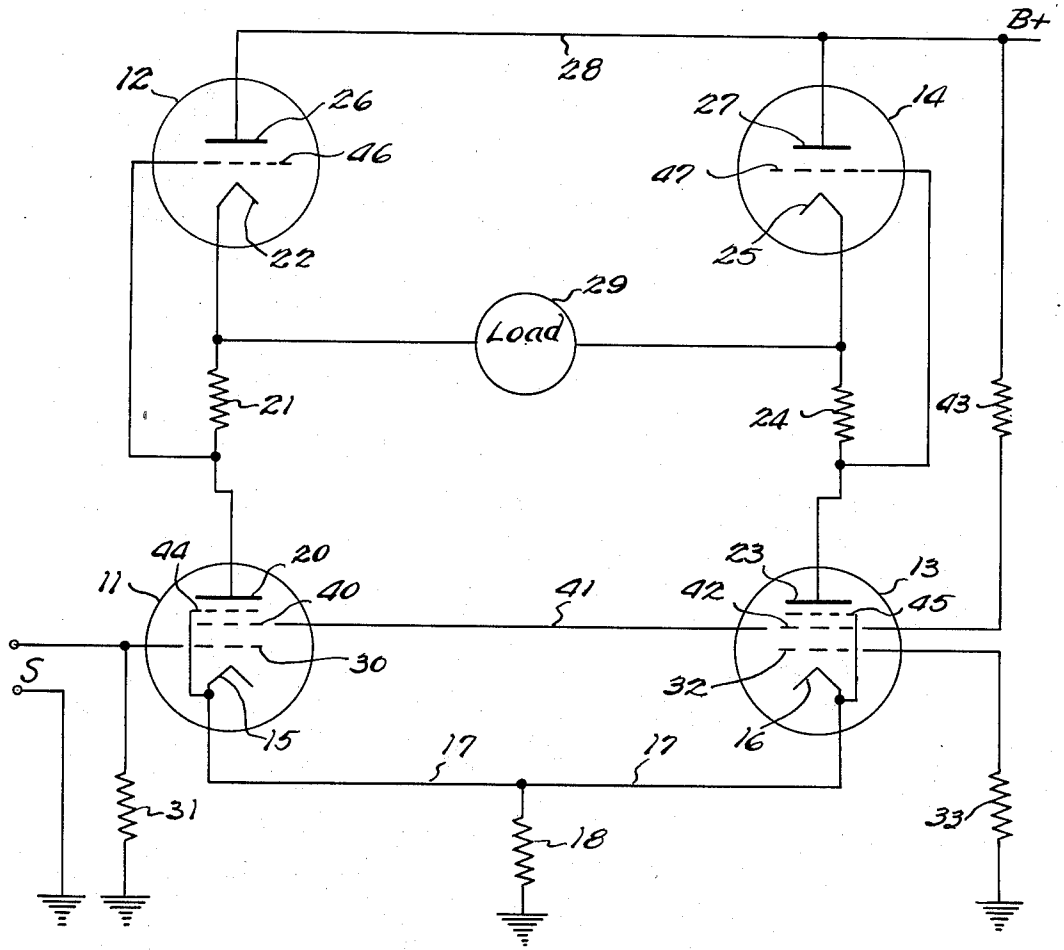
April 3, 1956 B. S. CAHILL 2,740,847

APPARATUS FOR CONTROLLING AMPLIFIER TUBES

Filed March 7, 1951

Fig. 1.



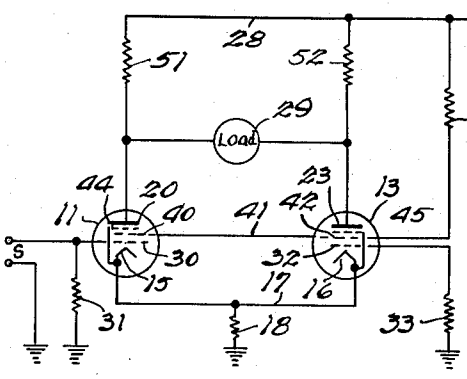


Fig. 2.

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2,740,847

APPARATUS FOR CONTROLLING AMPLIFIER TUBES

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Application March 7, 1951, Serial No. 214,347

1 Claim. (Cl. 179—171)

This invention relates to a method and apparatus for controlling amplifier tubes and, more particularly, to a direct current ampifier incorporating such method and apparatus. It is an object of the invention to provide an improved method and apparatus of that character.

In numerous applications of amplifier tubes, one of which is a direct current bridge circuit amplifier, it is desired that the total plate current of two tubes be maintained at a constant value while the relative value of the plate currents of the two tubes is varied by changes in the control grid voltage of one or both tubes. It is another object of the invention to provide an improved method and apparatus for obtaining this result.

According to one embodiment of the invention the screen grids of two tubes are connected together and the cathodes of the same two tubes are directly connected together. A battery or other suitable source of electrical energy and a series resistor of substantial resistance value are connected between the screen grids and the cathodes of the tubes. The battery and the resistor, as a unit, may be considered as constituting a power source of high internal resistance and hence of very poor voltage regulation. Practically, the resistance is made much greater than the cathode to screen grid resistance under normal operating conditions of the tubes and hence the battery and resistance serve as a substantially constant current source of electric energy. Accordingly, the total screen grid current of the two tubes is maintained at a substantially constant value. A control signal is applied to the control grid of one of the tubes while the control grid of the other tube is, in the simplest arrangement, maintained at a constant voltage.

Circuit constants are selected of such value that over the desired operating range of the tubes the plate current and the screen grid current in both tubes are determined by the screen grid voltage, to the exclusion of any substantial influence of variations in the plate voltages. This means that the plate current in either tube is maintained at a constant ratio to the corresponding screen grid current. It will be apparent that since the total screen grid current is maintained at a substantially constant value and since the plate currents are maintained proportional to the corresponding screen grid currents, the total plate current for the two tubes necessarily must remain constant. Accordingly when a change in the control signal applied to the control grid of one of the tubes causes an increase in plate current in one tube, there will be a corresponding and equal decrease in plate current in the other tube, all as will subsequently be explained in greater detail.

The maintenance of the total screen grid current of the two tubes at a substantially constant value obtains a constancy of the total plate current of the two tubes which is not readily obtainable even by relatively complex circuits involving voltage dividers and other known devices.

Accordingly, it is another object of this invention to

provide a simple, economical, and reliable circuit for maintaining the total plate current of two screen grid tubes at a substantially constant value.

The circuit is shown embodied in a direct current bridge circuit amplifier, certain features of which are disclosed and claimed in the application of Wilbert Parisoe, Serial No. 149,156, filed March 11, 1950, entitled "Direct Current Amplifier" and assigned to the same assignee as the present invention. The invention as applied to such an amplifier results in accurate control and stable operation while at the same time being of itself very simple, inexpensive and reliable.

Accordingly, it is another object of this invention to provide an improved direct current bridge circuit amplifier which is accurate, stable, inexpensive and reliable.

This invention, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the drawing, in which like parts are designated by like reference numerals,

Fig. 1 is a circuit diagram of a D. C. bridge amplifier constructed in accordance with one embodiment of the invention; and,

Fig. 2 is a circuit diagram of another D. C. bridge amplifier constructed in accordance with another embodiment of the invention.

Referring to the drawing, the D. C. bridge circuit shown in Fig. 1 is capable of producing currents in either direction through a load, the magnitude of the current varying linearly with the applied signal. The circuit employs four amplifier tubes **11**, **12**, **13** and **14**, each being situated in one of the four legs of a bridge circuit. The cathodes **15** and **16** of the tubes **11** and **13** respectively are connected together by a conductor **17** which is returned to ground through a resistor **18**.

The plate **20** of the tube **11** is connected or coupled through a resistor **21** to the cathode **22** of the tube **12**. Similarly, the plate **23** of the tube **13** is connected through a resistor **24** to the cathode **25** of the tube **14**, the resistors **21** and **24** preferably being of equal resistance value. The plate **26** of the tube **12** and the plate **27** of the tube **14** are connected together by a conductor **28** which in turn is connected to B+ as shown. It is understood of course that B+ is the positive terminal of a suitable voltage source having its negative terminal connected in this case to ground. A load device **29** has its terminals connected to the cathodes **22** and **25** of the tubes **12** and **14** respectively. The B+ voltage is therefore applied across two opposed corners of the bridge while the load device **29** is connected across the other two opposed corners of the bridge.

The load device **29** may be of various forms depending upon the purpose for which the bridge circuit is intended. The device may, for example, be a small motor or any one of various forms of indicating devices, such as a meter. The four tubes **11**, **12**, **13** and **14** may also be of many different types depending upon the particular application of the bridge circuit, and more than one tube may be contained in a single envelope. Where the bridge circuit is intended to drive a small motor it has been found to be satisfactory to combine the tubes **11** and **13** in a single envelope such as a 28D7 double pentode, and to combine the two tubes **12** and **14** in a single envelope such as a 6SN7 or a 12AU7 double triode.

A signal S is applied between the control grid **30** of the tube **11** and ground, a grid leak resistor **31** being provided for stability. Since a substantially constant current flows through the resistor **18** under normal operating conditions of the bridge circuit, as will subsequently be shown, it

will be apparent that if the resistor 18 is of suitable magnitude the cathode 15 of the tube 11 may be maintained positive at all times with respect to the grid 30. This is desirable in most applications in order to obtain more stable operation and substantially linear performance of the tube. If the signal is expected to vary, for example, over a range of 7 volts, from +3½ volts to −3½ volts, a resistance value may be selected for the resistor 18 such that the current passing therethrough causes a voltage drop of 5 volts to appear thereacross. In such case the voltage of the grid 30 with respect to the cathode 15 will vary over the range −5±3½, or −1½ to −8½ volts.

The control grid 32 of the tube 13, in the simplest form of the circuit, is maintained at a constant voltage level, the grid being connected to ground through a resistor 33 to prevent the accumulation of a static charge on the grid.

The screen grid 40 of the tube 11 is directly connected by a conductor 41 to the screen grid 42 of the tube 13, and the two screen grids are connected to B+ through a resistor 43. The purpose of connecting the screen grids in this manner will be explained subsequently.

Where the tubes 11 and 13 are pentodes, the suppressor grids 44 and 45 may be connected directly to the respective cathodes 15 and 16 as shown in the drawing.

The circuit components are so chosen that the screen grid voltage is sufficiently high relative to the plate voltage in each of the tubes 11 and 13 over the normal operating range of the circuit, that the screen grid voltage, in conjunction with the control grid bias, governs both the screen grid current and the plate current of these tubes, to the exclusion of any substantial effect of the plate voltages on the respective plate currents. The value of the plate current in each tube will accordingly be at a fixed ratio to the screen grid current of the same tube, both currents being functions of the screen grid voltage and of the control grid bias.

The primary objective of the invention may be considered as being to maintain the total plate current for the two tubes 11 and 13 at a constant value over the normal operating range of the circuit even though the control grid voltages vary, thereby altering the value of the plate current of the individual tubes. This means that when the voltage of the grid 30 is altered to increase or decrease the plate current of the tube 11, the plate current of the tube 13 must be altered equally and oppositely. For example, if the plate current of the tube 11 is increased by 5 milliamperes, the plate current of the tube 13 should be decreased by 5 milliamperes.

This is accomplished according to the present invention by maintaining the total screen grid current of these two tubes at a substantially constant value. Since the magnitude of the plate currents are individually held at a substantially fixed ratio to the corresponding screen grid current, the total plate current will, under these conditions, also be maintained at a substantially constant value. The maintenance of a constant total screen grid current is accomplished, in turn, by selecting a resistor 43 whose ohmic value is large compared to the effective cathode to screen grid resistance of the tubes 11 and 13 under normal operating conditions. It will be apparent that the B+ voltage is abnormally high for connection to the screen grids of the tubes 11 and 13 since this voltage is of such value as to supply the plate voltage for two series arranged tubes, namely, 11 and 12 or 13 and 14. The screen grids are maintained at voltages which are within the normal operating range of the tubes by virtue of the voltage drop across the resistor 43 caused by the passage of the total screen grid current therethrough.

The relatively high value of the B+ voltage for the screen grids, and the relatively large resistor 43 through which the total screen grid current passes, serve, in combination as a substantially constant current source of electrical energy. That is to say, as long as the effective resistance between the respective screen grids and the cathodes of the tubes are relatively small as compared to the ohmic value of the resistor 43, the total resistance in the screen grid circuit will vary by only a small percentage and the total screen grid current will be maintained substantially constant. To accomplish this, the constant current source causes the screen grid voltage to vary in opposition to changes in control grid voltage. As will subsequently be explained in detail, this characteristic of the circuit is enhanced if the amplification factor μ relative to the control grid and the screen grid is small for the tubes 11 and 13.

As explained above, the effect of artificially maintaining the total screen grid current at a constant value is to maintain the total plate current for the same two tubes substantially constant. At the same time, the change in plate current or screen grid current in tube 11, with a given change in control grid voltage, is reduced to half of what it would be if the screen grid voltage were held constant. This may best be explained by a simple example. Let it be assumed that the circuit is in balanced condition with the control grid 30 at a voltage of −5 volts. Let it be assumed further that the plate current in each of the tubes 11 and 13 is 10 milliamperes while the screen grid current is 2 milliamperes, and that the plate voltage of each tube is 52 volts and the screen grid voltage is 50 volts. If the voltage of the control grid 30 is now reduced to −6 volts the plate current I_p and the screen grid current I_{sg} of the tube 11 will tend to decrease by an amount ΔI_p and ΔI_{sg}, respectively, that is, such changes in the plate current and screen grid current would occur if the screen grid voltage remained constant.

However, the constant current source comprising the B+ voltage and the large resistor 43 respond to this tendency to reduce total screen current by the amount ΔI_{sg}, by raising the screen grid voltage of both tubes until the total screen grid current is substantially equal to its original value. Since the tubes respond substantially linearly, the rise in screen grid voltage will tend to increase the current in each tube by an amount equal to ½ ΔI_{sg}. The net result of these two effects is that the screen grid current of tube 11 will be decreased by the value ½ ΔI_{sg} while the screen grid current of the tube 13 will be increased by the same amount. Since the plate current I_p for each of the two tubes is at all times maintained at a constant ratio to the respective screen grid currents, as explained above, the plate current of tube 11 will be decreased by an amount equal to ½ ΔI_p while the plate current of tube 13 will be increased by the same amount.

When the voltage of the grid 30 is reduced, for example, to −6 volts the total screen grid current is actually reduced by a very minute amount. It is this slight reduction in the current through the resistor 43 which causes a substantial rise in the voltage of the screen grids because of the large ohmic value of the resistor 43. The rise in the screen grid voltage closely approaches the value which would recoup half of the drop in the screen grid current, ΔI_{sg}, of the tube 11, which would occur if the screen grid voltage were maintained constant. A like amount of increase in screen grid current is obtained in the tube 13 with the result that the total screen grid current and hence the total plate current remain substantially constant.

As stated above, a low μ characteristic, relative to the control grid and the screen grid, is desirable for the tubes 11 and 13 in the particular embodiment shown since the use of such tubes permits the desired plate current control to be obtained by relatively small changes in screen grid voltage. For example, if the tubes 11 and 13 are selected with a control grid to screen grid μ characteristic equal to 3, a decrease of 1 volt on the control grid 30 could be offset by a 3 volt change in screen grid voltage and, in the circuit shown, would actually be attended by an increase of only 1½ volts on the screen grids. The decrease in screen grid current and hence in plate current in the tube 11 will then be one-half of that which would result from a 1 volt decrease in bias of the

control grid if the screen grid voltage had remained constant. At the same time, the 1½ volt increase in screen grid voltage of the tube **13** will result in increased screen grid current and plate current in the tube **13**, these increases being equal but opposite to the changes in screen grid current and plate current in the tube **11**. It will be apparent that where the constant current source, comprising the B+ voltage and the resistor **43**, need alter the voltage of the screen grids by only 1½ volts in response to a 1 volt change in control grid bias, the source can maintain a more constant value of total screen grid current than if a more substantial change in screen grid voltage were required corresponding to the same change in control grid bias. In the illustrated embodiment of the invention the required change in screen grid voltage is, in fact, a direct measure of the minute change in total screen grid current necessarily accompanying the corresponding change in control grid voltage. Accordingly, a low control grid to screen grid μ characteristic is desirable for the tubes **11** and **13**.

When the two tubes **11** and **13** are balanced, that is, when their plate currents are equal, the voltage drops across the resistors **21** and **24** are equal and, accordingly, the control grids **46** and **47** of the tubes **12** and **14** are equally biased. The plate current through the two tubes **12** and **14** will, therefore, be equal and as a result no current will pass through the load device **29**.

If the current through the tube **11** is now increased and the current through the tube **13** decreased by an equal amount, the voltage drop across the resistor **21** will be greater than the drop across the resistor **24**. Consequently, the grid bias of the tube **12** will be more negative than that of the tube **14** with the result that the tube **14** will pass a greater current than the tube **12**. It will be apparent that under these conditions a current will pass through the load device **29** since the bridge is unbalanced. The opposite result will, of course, be obtained if the current through the tube **13** is increased while the current through the tube **11** is decreased.

The resistors **21** and **24** are preferably made equal to the reciprocal of the transconductance of the respective tubes **12** and **14**. The use of biasing resistors of such value will result in the plate currents of the tubes **12** and **14** varying by amounts equal to the change in currents passing through the resistors **21** and **24** and hence equal to the changes in the plate currents of the tubes **11** and **13**. Specifically, if the plate current of the tube **11** is increased by 2 milliamperes and the plate current of the tube **13** is decreased by 2 milliamperes, the 2 milliamperes increase in current through the resistor **21** will produce a change in bias on the grid **46** such that the plate current through the tube **12** will be reduced by 2 milliamperes, and the decrease of 2 milliamperes in the current passing through the resistor **24** will raise the voltage of the grid **47** with respect to the cathode **24** of the tube **14** by such an amount that the plate current in the tube **14** will increase by 2 milliamperes. It will be apparent that by proper selection of the zero or balance point of the bridge, this arrangement will permit a maximum range of linear performance of the bridge. This portion of the circuit is disclosed and claimed and is explained in greater detail in application Serial No. 149,156 referred to above.

Resistors **21** and **24** may also be used of values in excess of the reciprocal of the transconductance of the corresponding tubes **12** and **14**. The plate current of the latter tubes will then vary more steeply than the plate currents of the tubes **11** and **13** and a greater change in current through the load device **29** will be obtained for a given change in the voltage of the grid **30** of the tube **11** when the bridge is operating near its balanced condition. However, the range over which this increased sensitivity of the bridge may be obtained is limited by the maximum change in plate current which can be obtained in the tubes **12** and **14**. Under the conditions last specified the plate current in one of the upper tubes, for example tube **14**, will be reduced to zero before the plate current in the tube **11** reaches zero. Accordingly, a further reduction in the voltage of the grid **30** will produce no further change in the plate current of the tube **14** and the sensitivity of the bridge will be greatly reduced through the remainder of its operating range, namely, to the point at which the plate current in the tube **11** reaches zero.

Thus, with the resistance of the resistors **21** and **24** being greater than the reciprocal of the transconductance of the corresponding tubes **12** and **14**, increased sensitivity of the bridges is obtained near the point of balance but the operation of the bridge is not linear throughout its entire range.

The D. C. bridge amplifier disclosed in Fig. 2 is identical to that appearing in Fig. 1 with the exception that a pair of resistors **51** and **52** are substituted for the tubes **12** and **14**. The resistors **21** and **24**, shown in Fig. 1 for the purpose of controlling the tubes **12** and **14**, are of course eliminated in Fig. 2 along with the connections between the plates of the tubes **11** and **13** and the grids of the tubes **12** and **14**. The remaining portions of the two circuits are identical, and like reference numerals are employed in the two figures for the corresponding elements of the circuits.

The current through the load **29** in Fig. 2 is dependent upon the difference in plate current between the two tubes **11** and **13** but, rather than being substantially equal to this difference, as in the circuit shown in Fig. 1, it is at most equal to one-half of the difference, depending on the resistance values of the resistors **51** and **52** and of the load device **29**. For example if the current in the tube **11** is 12 milliamperes while the plate current of the tube **13** is 8 milliamperes the current through the load **29** will not be 4 milliamperes as would be the case in the circuit shown in Fig. 1 but instead will be at the most only 2 milliamperes. The reason for this is, of course, that the resistors **51** and **52** operate only passively and at best maintain the respective currents therethrough at equal values while the tubes **12** and **14** in the circuit shown in Fig. 1 actually decrease the current in the upper leg adjoining the lower leg in which current is increased, and vice versa. The circuit shown in Fig. 2 is therefore less sensitive than the circuit shown in Fig. 1, all as is well understood in the art, but eliminates the necessity of two of the tubes in the circuit shown in Fig. 1 in favor of relatively inexpensive resistors.

It will be apparent from the above explanation of the circuits shown in Figs. 1 and 2, that the method and apparatus described for maintaining the total plate current of the two tubes **11** and **13** substantially constant is particularly well adapted to use in bridge circuits. However, this method and apparatus are well adapted to many different applications. One of these is, broadly, the mixing of two independent signals. The grid **32** may, for example, receive a second control signal entirely separate and independent of the signal S applied to the control grid **30**. The signal applied to the control grid **32** may be used to supplement the effect of the basic signal applied to the control grid **30** or may be used to correct or partially offset some deficiency in the latter signal. Also, the circuit portion involving the two tubes **11** and **13** and the controls therefor, may be used to determine phase relationship between two alternating current signals.

Other means than those shown in the drawing and described above may be employed for maintaining the total screen grid current and hence the total plate current of the tubes **11** and **13** substantially constant. The means disclosed are considered a practical way of obtaining the desired result but the invention is not to be considered as being limited thereto.

Accordingly, while particular embodiments of the invention have been shown, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, and it is, therefore, con-

templated to cover by the appended claims any such modifications as fall within the true spirit and scope of the invention.

The invention having thus been described, what is claimed and desired to be secured by Letters Patent is.

A pair of screen grid tubes arranged generally in parallel, and means for maintaining the total plate current of said pair of tubes substantially constant comprising a conductor connecting the cathodes of said tubes, a conductor connecting the screen grids of said tubes, and a source of substantially constant current electric energy connected between said screen grids and said cathodes, said source including a generator of electrical energy and a resistor in series therewith, said resistor having a resistance value at least four times the effective cathode to screen grid resistance of said pair of tubes in parallel under normal operating conditions thereof.

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