March 10, 1953 W. PARISOE 2,631,198

DIRECT CURRENT AMPLIFIER

Filed March 11, 1950 2 SHEETS—SHEET 1

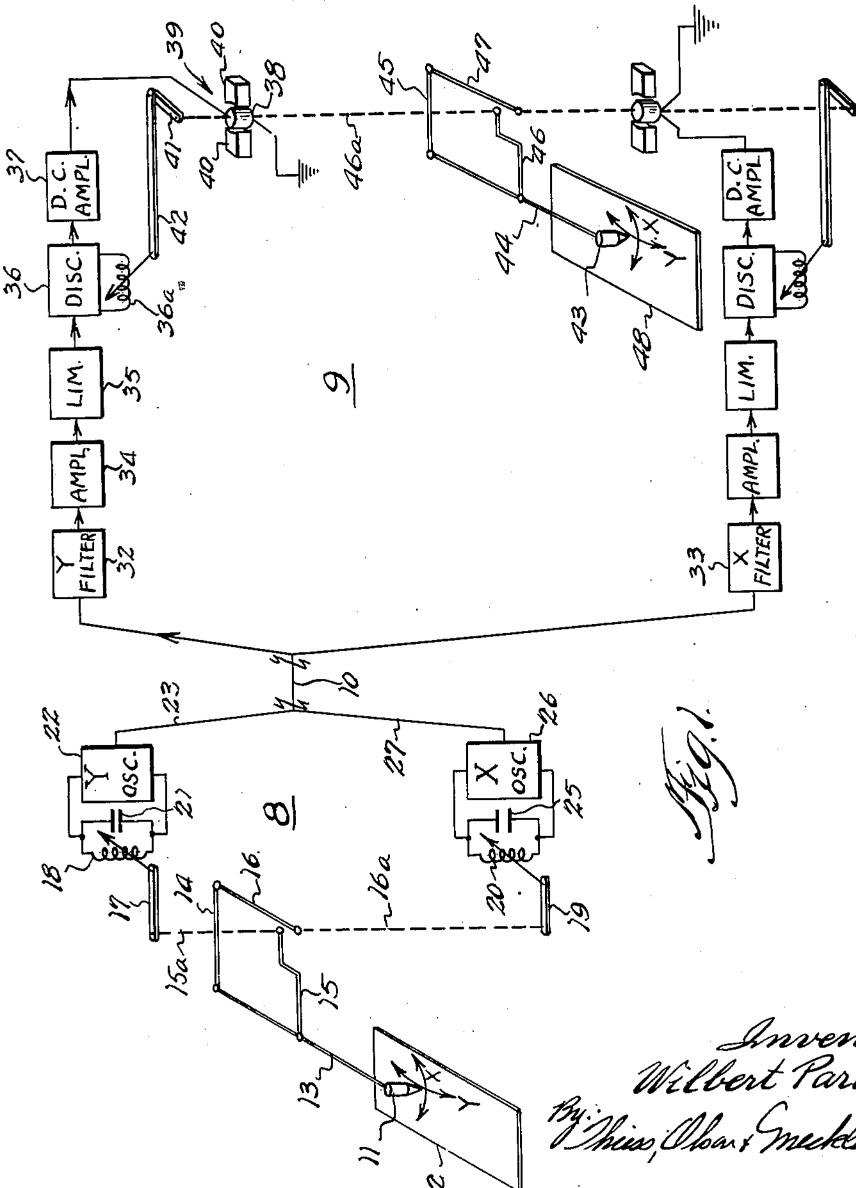

Fig. 1.

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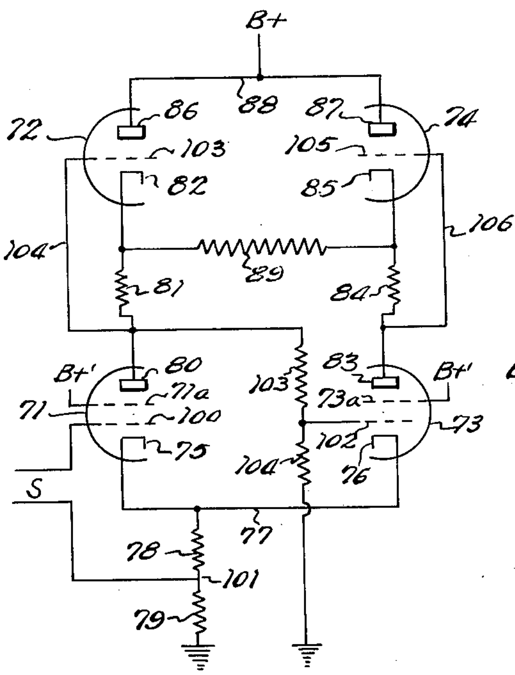

Fig. 2.

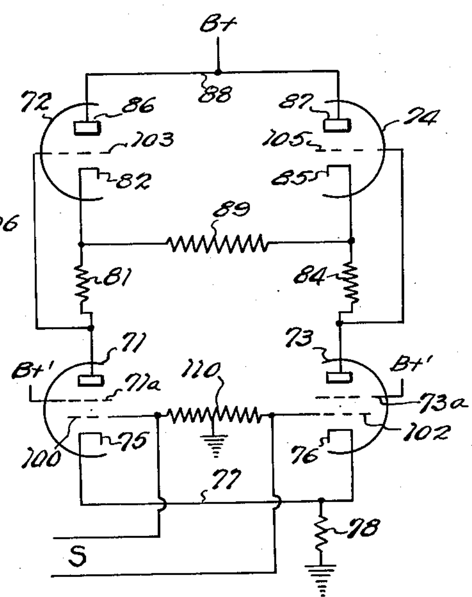

Fig. 3.

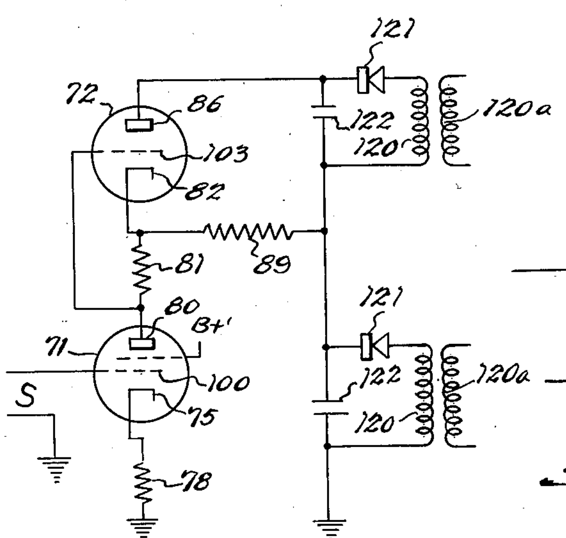

Fig. 4.

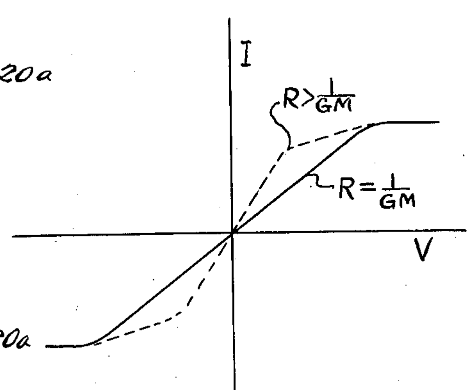

Fig. 5.

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UNITED STATES PATENT OFFICE

2,631,198

DIRECT CURRENT AMPLIFIER

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Application March 11, 1950, Serial No. 149,156

2 Claims. (Cl. 179—171)

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This invention relates to direct current amplifiers capable of delivering an output current of reversible direction to a load and, more particularly, to bridge circuit amplifiers of this character having electron tubes in at least two, series arranged, bridge legs. It is an object of the invention to provide an improved amplifier of that character.

In one common form, a bridge circuit used as an amplifier has four legs containing impedance devices with a power source connected across two opposed corners of the bridge. A load device is connected across the other two opposed corners and the current therethrough may be controlled by variation of the impedance value of any one or more of the impedance devices forming the four legs of the bridge.

Where a substantial voltage or power amplification is required, a vacuum tube is employed as the impedance device for the variable impedance leg of the bridge and where greater efficiency and amplification are desired each of the four bridge legs includes a tube, all as well understood in the art. A problem arises, however, in the control of any two tubes which are arranged in series between the power source connections because of the fact that such two tubes operate at different voltage levels and, accordingly, cannot be directly driven by a single D. C. signal voltage, that is, the signal voltage cannot be applied directly across the grid and cathode of both tubes.

It has previously been proposed to solve this problem by driving the lower voltage level tubes directly and utilizing additional tubes for driving the higher voltage level tubes. This arrangement is satisfactory operationally but has the obvious disadvantage of requiring two extra tubes. The present invention is concerned with the control of both the high and low voltage level tubes without the necessity of additional tubes.

According to one embodiment of the present invention, the tube operating at the lower voltage level is driven directly by the signal while the other tube, arranged in series therewith and operating at a higher voltage level, is driven by the voltage across a biasing resistor arranged in the plate circuit of the lower voltage level tube. The grid voltage, and hence the plate current, of the high voltage level tube is thereby varied negatively or oppositely with respect to the plate current of the lower voltage tube, that is, when the plate current of the lower voltage tube increases, the plate current of the higher voltage tube decreases. The relative values of these two plate currents can be maintained such that their sum remains constant by selection of

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a biasing resistor having a proper value with respect to the characteristics of the driven or high voltage level tube. This relation, or some selected variation therefrom, is desirable in most amplifier bridge circuits and the method of determining the proper value of the biasing resistor, for the particular results desired, will be explained subsequently herein.

An amplifier incorporating the various features of the invention is well adapted to use in tele-autographic apparatus since it is capable of handling the necessary power while employing standard receiver tubes and since it is responsive to direct current signals which fluctuate at speeds varying from zero cycles per second to the frequencies attending the most rapid handwriting. The amplifier will in fact respond accurately to frequencies in the audio range or higher. Accordingly, the various embodiments of the invention shown in the drawings will be described below as particularly adapted to that use, but it will be understood that the invention is not limited thereto.

It is another object of the invention to provide an improved direct current bridge circuit amplifier having a large amplification factor.

It is another object of the invention to provide an improved direct current bridge circuit amplifier having very stable characteristics about the null, or zero load current region.

It is another object of the invention to provide an improved direct current bridge circuit amplifier having high power efficiency.

It is another object of the invention to provide an improved direct current bridge circuit amplifier having the advantages specified above while being inexpensive to manufacture and reliable in operation.

It is another object of the invention to provide an improved direct current bridge circuit amplifier having an amplifier tube in two bridge legs arranged in series between terminals of a voltage source, one of these tubes driving the other tube, without the necessity of additional control tubes, such that the sum of the plate currents of the two tubes is maintained substantially constant.

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 drawings, and its scope will be pointed out in the appended claims.

In the drawings, in which like parts are indicated by like reference numerals:

Fig. 1 is a circuit diagram of tele-autographic apparatus in which a D. C. bridge amplifier embodying the various features of the invention may be employed to advantage;

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

Fig. 3 is a circuit diagram similar to Fig. 2 but illustrating another method of introducing the control signal;

Fig. 4 is a circuit diagram illustrating another form of amplifier constructed in accordance with the invention; and

Fig. 5 is a graph showing typical characteristics of an amplifier constructed in accordance with the invention.

The tele-autographic apparatus illustrated in Fig. 1 may be similar to that described and claimed in the application of Robert Adler, Serial No. 81,709, filed March 16, 1949, entitled Improvement in Follow-Up Apparatus and Systems, issued January 29, 1952, as Patent No. 2,583,720, and assigned to the same assignee as the present invention, and, accordingly, will be described only briefly herein.

The apparatus comprises a transmitting station **8** and a receiving station **9** connected by a transmission line **10**. The transmitting station includes a stylus **11** with which a message or other form of intelligence may be written or drawn on a writing surface **12**. The movements of the stylus **11** are transmitted by a rigid arm **13** to pivotally connected links **14**, **15**, and **16**, the latter two links **15** and **16** being pivotable about aligned, fixed axes **15***a* and **16***a* respectively. The link **15** is mechanically connected through an arm **17** to the movable element of a variable inductance element **18**, whereby pivotal movement of the link **15** will cause a variation in the inductance of the coil **18**.

Similarly, the link **16** is connected through an arm **19** to a variable inductance coil **20** and pivotal movement of the link **16** causes a change in the inductance of that coil.

It will be apparent upon inspection of the arm and link arrangement that movement of the stylus along the curved X axis indicated on the writing surface **12** will leave the link **15** stationary but will cause a pivotal movement of the link **16** and a consequent change in the inductance of the coil **20**. Similarly, a movement of the stylus **11** along the curved Y axis indicated on the writing surface **12** will leave the link **16** stationary but will cause a pivotal movement of the link and a consequent change in the inductance of coil **18**. The link mechanism including the links **13**, **14**, **15**, and **16**, shown schematically in Fig. 1, is more fully described and is claimed in a copending application of Robert Adler, entitled Improvement in Translating Apparatus and Follow-Up Systems, filed April 2, 1949, having Serial No. 85,236, issued January 29, 1952 as Patent No. 2,583,535 and assigned to the same assignee as the present invention.

The variable inductance coil **18** in combination with a fixed capacity condenser **21** forms a resonant circuit for controlling the output frequency of an oscillator **22**, which will be termed herein the Y oscillator, since its output frequency is determined by the position of the stylus **11** along the indicated Y axis on the writing surface **12**. The output of the Y oscillator **22** is carried by a conductor **23** to the transmission line **10** for transmission to the receiver station **11**.

Similarly, the variable inductance coil **20** in combination with a fixed capacity condenser **25** forms a resonant circuit for controlling the frequency of an X oscillator **26**. The output frequency of the X oscillator, since it is controlled by the variable inductance coil **20**, is a function of the position of the stylus **11** along the indicated X axis on the writing surface **12**. The output of the X oscillator **26** may be connected by a conductor **27** to the same transmission line **10** which carries the signal from the Y oscillator **22**.

At the receiving station, the two signals are separated by the filters **32** and **33**, the Y filter **32** passing only the Y signal frequency band while the X filter **33** passes only the X frequency band.

The Y signal passes from the Y filter **32** through an amplifier **34** and a limiter **35** to a discriminator **36**.

The discriminator **36** may be of the type described and claimed in application Serial No. 81,709 referred to above, and, accordingly, will not be described in detail herein. For the purposes of this application, it will be sufficient to say that a direct current signal voltage is produced thereby whose magnitude is a function of the frequency of the incoming signal from the limiter **35** and of the inductance of a coil **36***a* forming a part of the discriminator circuit. For every frequency within the predetermined band of Y signals, there is a corresponding value of inductance of the variable inductance coil **36***a* which will result in a zero signal output from the discriminator **36**.

The output signal of the discriminator **36** passes through a D. C. amplifier **37** and to the rotor **38** of a D. C. motor **39** whose field may be produced by suitable permanent magnets **40**.

The motor **39** operates a series of interconnected links **41** to **42** to vary the inductance of the coil **36***a* as is schematically indicated in Fig. 1. The motor **39** also drives a receiver stylus **43** through a linkage system including a rigid arm **44** and links **45**, **46**, and **47**. More specifically, the rotor **38** of the motor **39** is mechanically connected to the link **41** and the link **46**, all of these elements being rotatable about a fixed axis **46***a*. When the rotor **38** rotates through a given angle, the link **46** will rotate through the same angle and cause the stylus **43** to move along the curved Y axis indicated on a receiver station writing surface **48**.

In order that the operation of the circuit, shown in Fig. 1, may be understood to sufficient degree to permit a full appreciation of the present invention, an operation of the apparatus shown in Fig. 1 will now be described. Let it be assumed that the receiver stylus **43** and the transmitter stylus **11** occupy corresponding positions along their respective Y axes. Under these conditions, the variable inductance coil **36***a* has an inductance of such value and the frequency of the Y signal received from the transmitter is of such value that no signal is transmitted from the discriminator **36** to the D. C. amplifier **37** Accordingly, the motor **39**, the links **41** and **42** and the receiver stylus **43** remain stationary.

If now the transmitter stylus **11** is displaced along the Y axis on the writing surface **12**, the inductance of the coil **18** is changed and the output of the Y oscillator **22** will be of a different frequency than before. Accordingly, the Y signal as received by the discriminator **36**, because of its change in frequency, will cause a signal output from the discriminator which is amplified by the amplifier **37**. The motor **39** is thus energized causing movement of the receiver stylus **43** along the Y axis on the writing surface **48** toward a position corresponding to the new position of the transmitter stylus 11. When the stylus 43 has reached this corresponding position, the inductance of the coil 36a will have been changed by movement of the links 41 and 42 until it is of such value that at the frequency of the incoming Y signal the discriminator output signal is zero, all as explained in detail in application Serial No. 81,709 referred to above.

Thus it is seen that the receiver stylus 43 will follow the movements of the transmitter stylus 11 along the corresponding Y axes

The receiving station includes a circuit for the incoming X signal similar to the Y signal circuit described immediately above. The X signal circuits and apparatus cause the receiver stylus 43 to assume positions along the indicated X axis on the writing surface 48 which correspond to the positions of the transmitter stylus 11 along the indicated X axis on the writing surface 12. Since the circuits, the apparatus, and the operation thereof are identical to the Y signal circuits apparatus and operation described above, a detail description thereof will not be given herein.

It will be apparent to those skilled in the art that the signals sent from the discriminators to the corresponding D. C. amplifiers are, for practical reasons, of too small a magnitude to drive the motor 39 of the Y signal circuit or the corresponding motor of the X signal circuit. Accordingly, a D. C. amplifier is required for each circuit. These amplifiers must be able to handle signal variations of a frequency corresponding to the rapidity of reversal of movement of the transmitter stylus 11. In the case of ordinary handwriting, variation in the D. C. signals fed to the D. C. amplifier normally fall within a range of from 0 cycles per second to approximately 15 cycles per second Accordingly, where the D. C. amplifier is applied to such a circuit as that shown in Fig. 1, it must be able to handle these frequencies. In other applications, the amplifier may be called upon to respond to frequencies of a considerably higher range.

In many applications, such as that shown in Fig 1, it is also desired that the amplifier have a substantial amplification factor in order that a voltage signal of substantial magnitude may be fed to the motor 39 and the stylus 43 be driven rapidly to follow accurately the movements of the transmitter stylus 11.

Still another feature which is desired in the application shown in Fig. 1 is high amplifier efficiency. In some applications, the required power output of a D. C. amplifier may be on the order of milliwatts. In the application of the D. C. amplifier shown in Fig. 1, however, the desired power output is in the order of watts. Accordingly, high efficiency is desired for various reasons, perhaps the most important of which is to permit use of standard and hence low cost circuit elements such as, for example, amplifier tubes. Another desirable result of high efficiency in the D. C. amplifier is the reduction in operating power, this being of very substantial significance where the receiving station of the tele-autographic apparatus shown in Fig. 1 is a portable unit operating on batteries.

The various D. C. amplifiers or bridge circuits, illustrated in Figs. 2, 3, and 4, are well suited for application as the D. C. amplifier 37 of the tele-autographic apparatus shown in Fig. 1. Any of these three amplifiers have relatively high efficiency and can produce a power output of several watts and a variable polarity output voltage very accurately proportional to a signal voltage which may alternately increase and decrease with a rapidity of from zero cycles per second to frequencies lying in the range of audio frequencies or even radio frequencies.

The circuit appearing in Fig. 2 employs four amplifier tubes 71, 72, 73, and 74, each being situated in one of four legs of a bridge circuit. The cathodes 75 and 76 of the tubes 71 and 73, respectively, are connected together by a conductor 77 which is returned to ground through a pair of resistors 78 and 79. The plate 80 of the tube 71 is connected or coupled through a resistor 81 to the cathode 82 of the tube 72. Similarly, the plate 83 of the tube 73 is connected through a resistor 84 to the cathode 85 of the tube 74. The plate 86 of the tube 72 and the plate 87 of the tube 74 are connected together by a conductor 88 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 89 has its opposite ends connected to the cathodes 82 and 85 of the tubes 72 and 74, respectively. The B+ voltage is, therefore, applied across two opposed corners of the bridge while the load device 89 is connected across the other two opposed corners of the bridge.

When the amplifiers shown in Figs. 2, 3, and 4 are applied to tele-autographic apparatus such as that shown in Fig. 1, the load 89 may be the motor 39.

The four tubes 71, 72, 73, and 74 may be of many types depending on the particular application of the bridge circuit and more than one tube may be contained in a single envelope. In the application described above, it is found to be satisfactory to combine the tubes 71 and 73 in a single envelope, such as a 28D7 pentode, with the screen grids 71a and 73a connected to B+' as shown, and to combine the two tubes 72 and 74 in a single envelope such as a 6SN7 or a 12AU7. The screen grids 71a and 73a are indicated as being connected to a voltage source other than the B+ to which the plates of the tubes 72 and 74 are connected since the latter would normally be of a higher voltage than should be applied to the screen grids 71a and 73a, as is well understood in the art.

A signal S is applied between the grid 100 of the tube 71 and a point 101 intermediate the two resistors 78 and 79. The resistor 78 is provided in order to maintain the grid 100 negative with respect to the cathode 75. If the signal is expected to vary, for example, over a range of seven volts, from $+3\frac{1}{2}$ volts to $-3\frac{1}{2}$ volts, a resistance value might be selected such that the plate and screen currents for the two tubes 71 and 73, in passing through the resistor, cause a voltage drop of 5 volts to appear thereacross, resulting in the cathode 75 of the tube 71 being maintained at a voltage level 5 volts above that of the point 101. Accordingly, the voltage of the grid 100 with respect to the cathode 75 would vary over the range $-5\pm3\frac{1}{2}$, or $-1\frac{1}{2}$ to $-8\frac{1}{2}$ volts. As will later become apparent, the current passing through the resistor 78 will at all times be substantially constant and in any event any small deviations will have no effect other than to make the response of the circuit slightly nonlinear. The function of the resistor 79 will be explained subsequently.

When the signal voltage is zero, the voltages of the grids 100 and 102 of the respective tubes

71 and 73, and hence the plate currents of these tubes, are preferably maintained at equal values. When the voltage of the grid 100 is made more positive, to increase the current through the tube 71, it is desired, as is well understood in the art, that an equal but opposite signal be applied to the grid 102 of the tube 73, that is, the voltage of the grid 102 should be made more negative by an equal amount to produce a corresponding decrease in the current passed by the tube 73. In the circuit shown in Fig. 2, this is accomplished by means of a conventional voltage divider.

A resistor 103 is connected at one end to the grid 102 of the tube 73 and at its other end to the plate 80 of the tube 71, as shown. The grid 102 is connected also through another resistor 104 to ground, as shown. The two resistors 103 and 104 constitute a voltage divider having imposed thereacross the voltage between the plate 80 of the tube 71 and ground.

When a change in signal voltage makes the grid 100 of the tube 71 more positive, the current through the tube 71 increases and the additional current must pass through the load resistor 89 as will subsequently become more apparent. The voltage drop across this resistor and the increased voltage drop across the resistor 81 cause the plate 80 to become more negative, and since this voltage appears across the voltage divider resistors 103 and 104 the voltage across the resistor 104 will be smaller and the voltage of the grid 102 will be lower. The current through the tube 73 will, accordingly, be reduced, and by proper selection of the resistors 103 and 104, as is well understood in the art, the voltage of the grid 102 can be made to vary equally with but in opposition to the voltage of the grid 100 whereby when the plate current of the tube 71 is increased by one milliampere, the plate current of the tube 73 will be decreased by one milliampere and vice versa.

If desired, the voltages of the grids 100 and 102 need not vary equally and oppositely but the voltage of the grid 102 can be made to vary in accordance with an opposite or negative linear function of the voltage change of the grid 100.

It will be immediately apparent that the voltage of the grid 102 can approach but cannot reach ground voltage. Accordingly, in order to permit the voltage of the grid 102 to be maintained negative with respect to the cathode 76 (say −5 volts with zero signal voltage as suggested above) the resistor 79 is connected between the point 101 and ground. This resistor provides a substantially constant, positive bias to the point 101 and the voltage of the grid 102 can be made to vary about the voltage level of the point 101, as does the voltage of the grid 100.

With the plate currents of the tubes 71 and 73 varying inversely and preferably by equal amounts with any given change in signal voltage, as described immediately above, it will be apparent that any change in signal voltage will cause a change in the current passing through the load 89. However, a greater change in current through the load resistor can be obtained for a given change in signal voltage by properly varying the grid voltages and hence the plate currents of the other two tubes 72 and 74. Under balanced conditions, with zero signal voltage, for example, the plate currents of all four tubes will preferably be equal and no current will pass through the load 89. When the plate current of the tube 71 is increased by a signal variation, the current passed by the tube 72 should be diminished while the current carried by the tube 74 should be increased as this will make the bridge circuit more sensistive than if the plate currents of only the tubes 71 and 73 are varied.

It may be desirable under certain circumstances to make the plate current of the tube 72 equal at all times to the plate current of the tube 73, and the current of the tube 74 equal to that of the tube 71. In other cases, it may be desired that the currents of the tubes 72 and 74 be made to vary more widely than the currents of the tubes 71 and 73 for a given change in signal voltage. It is with the proper control of the various grids, operating at substantially differing voltage levels, that the present invention is primarily concerned.

It is apparent upon inspection of Fig. 2 that the signal S cannot be applied directly across the grid and cathode of both the tube 71 and the tube 72 since the tube 72 operates at a much higher voltage level than the tube 71. An obvious solution to this problem would be to provide another tube, controlled by the signal voltage and arranged to drive the grid 103 of the tube 72.

In the embodiments of the invention illustrated in Figs. 2, 3, and 4, the grid of the tube 72 is driven by the tube 71 without the necessity of an additional tube for that purpose.

The grid 103 of the tube 72 is connected by a conductor 104 to the plate 80 of the tube 71, and, accordingly, its voltage will always be the same as that of the plate 80. However, the cathode 82 of the tube 72 is connected to the plate 80 of the tube 71 through a biasing resistor 81. It will be immediately apparent that with any current passing through the tube 71 and hence the biasing resistor 81, the grid 103 of the tube 72 will be negative with respect to the cathode 82 of the same tube. It will also be apparent that as the plate current of the tube 71 increases, the negative bias of the grid 103 becomes greater with a resultant reduction of plate current in the tube 72. Similarly, as the plate current of the tube 71 decreases, the negative bias of the grid 103 becomes less and the plate current of the tube 72 increases.

The grid 105 of the tube 74 is similarly connected by a conductor 106 to the plate 83 of the tube 73. The biasing resistor 84 maintains the grid 105 negative with respect to the cathode 85 and as the plate current of the tube 73 increases the current in the resistor 84 increases and the grid 105 is made more negative with respect to the cathode 85, thereby reducing the plate current of the tube 74. Similarly, as the plate current of the tube 73 decreases, the plate current of the tube 74 increases.

The circuit shown in Fig. 3 is identical to that shown in Fig. 2 with the exception of the means for applying inverse signals to the grids 100 and 102 of the tubes 71 and 73, respectively. In Fig. 3 a signal S is applied across a resistor 110 having its two ends connected to the grids 100 and 102 of the tubes 71 and 73 respectively. The center point of the resistor 110 is connected to ground, as shown. Connecting the center point to some point on the bridge circuit of suitable voltage level causes the potential of the ends of the resistor 110, and hence the grids 100 and 102 to vary equally and inversely. Connection of the resistor to ground as shown in Fig. 3 causes the cathodes 75 and 76 to be maintained positive with respect to the respective grids 100 and 102 by virtue of the voltage drop across the resistor 78 connecting these cathodes to ground. It will be immediately apparent that a signal of one polarity will cause the grid 100 to become more positive and the grid 102 to become more negative by equal amounts while a signal of the reverse polarity will cause the grid 102 to become more positive and the grid 100 to become more negative by equal amounts.

This circuit for applying equal inverse signal voltages to the grids 100 and 102 has the advantage of simplicity as compared to the circuit shown in Fig. 2. On the other hand, the arrangement shown in Fig. 3 utilizes only one-half of the available signal voltage and, accordingly, is not as satisfactory where only a small signal voltage is available.

The actual ohmic values of the resistors 81 and 84 with respect to the characteristics of the tubes employed in the circuits shown in Figs. 2 and 3 have a controlling influence upon the characteristics of the bridge circuit. Frequently a linear performance of the circuit over a maximum range is desired for various reasons well recognized in the art. This can be obtained by using resistors 81 and 84 having ohmic values equal to

$$\frac{1}{g_m}$$

where g_m is the transconductance of the respective tubes 72 and 74. With resistors 81 and 84 having such values, an increase of say 2 milliamperes in the plate current of the tube 71 will be accompanied by a decrease of 2 milliamperes in the plate current of the tube 72. The plate current of the tube 73 in Figs. 2 and 3 will also be reduced by 2 milliamperes, by virtue of the voltage divider 103—104 of Fig. 2 or the resistor 110 of Fig. 3, and, as a result of the reduced voltage drop across resistor 84, the plate current of the tube 74 will be increased by the same amount.

The current through the load 89 will be equal to the difference in the plate currents of the tubes 71 and 72, or of the tubes 73 and 74. The load current is, therefore, a linear function of the plate current of the tube 71 and, accordingly, a linear function of the signal voltage S. As the current through the tubes 71 and 74 continues to increase and the current through the tubes 72 and 73 continues to decrease, the voltage drop across the load resistor will continue to follow this function until the plate current through the tubes 72 and 73 has reached zero. At this point, with a properly designed circuit, the plate current through the tubes 71 and 74 will have reached a near maximum value. Any further change in the signal voltage in the same direction will cause relatively little change in the current through the load 89 since the current through the tubes 72 and 73 has already become zero.

This characteristic of the circuit may be visualized more clearly in the solid curve designated

$$R=\frac{1}{g_m}$$

in Fig. 5, in which the load current I is plotted against the voltage V appearing on the grid 100 of the tube 71. It will be seen in Fig. 5 that by making the value of the resistors 81 and 84 equal to the reciprocal of the transconductance of the respective tubes 72 and 74, a substantially linear output is obtained over almost the entire operating range of the circuit.

If a linear performance of the amplifier or bridge circuit is not essential, it is possible to obtain an output which is greater with respect to the signal voltage than is available with the resistors 81 and 84 being equal to the reciprocal of the transconductance of the respective tubes 72 and 74. This is accomplished by making these resistors of somewhat higher resistance value. The characteristic curve resulting from such an arrangement is shown as a dotted curve in Fig. 5 and is indicated by the expression

$$R>\frac{1}{g_m}$$

The steeper portion of this curve, namely, that portion near the indicated vertical coordinate, is made steep by the fact that a given change in signal voltage produces a proportionate change in the plate current in the tubes 71 and 73, but produces corresponding changes in the plate currents of the tubes 72 and 74 which are greater than the changes appearing in the tubes 71 and 73. More specifically, if the plate current through the tube 71 is increased by two milliamperes, for example, and the plate current in the tube 73 is reduced by two milliamperes, the plate current in the tube 74 may be increased by three or perhaps four milliamperes, for example, while the plate current through the tube 72 is decreased by three or four milliamperes. The net result will, of course, be a current I through the load 89 which is greater than that which would have appeared if the plate currents of the tubes 72 and 74 had varied equally with the plate current of the tubes 71 and 73, the latter being the case when the resistors 81 and 84 are equal to the reciprocal of the transconductance of the respective tubes 72 and 74.

The increased response of the tubes 72 and 74, caused by the biasing resistors being greater than the reciprocal of the transconductance of the respective tubes 72 and 74, results in the plate current of one of the tubes 72 and 74 reaching a maximum desired value and the plate current of the other of these tubes becoming zero, before the tubes 71 and 73 have reached the condition of maximum or zero plate current. This point is indicated by the hump in the dotted curve in Fig. 5. It will be readily understood that as the signal voltage is varied beyond the value corresponding to this hump, no substantial change will appear in the plate currents of the tubes 72 and 74 and, accordingly, the further change in the current through the load 89 is the result of the respective changes in the plate currents in the tubes 71 and 73 only. Accordingly, the curve flattens considerably to a slope which is less than that of the solid curve shown in Fig. 5.

The use of biasing resistors 81 and 84 having resistance values greater than the reciprocal of the transconductance of the corresponding tubes 72 and 74 results, then, in a nonlinear response but causes a greater amplification over at least part of the operating range, especially in the operating range adjacent the zero or neutral signal voltage. This arrangement is then more satisfactory where a linear operating characteristic is not essential and greater amplification is desired especially over the operating range surrounding the zero or neutral signal voltage.

The curves shown in Fig. 5 are somewhat idealized as applied to the circuit shown in Fig. 2 since the voltage divider 103—104 used to control the grid 102 of the tube 73 in that circuit results in a nonlinear performance of the circuit under some conditions.

Another type of bridge circuit is shown in Fig.

4, this circuit employing voltage sources in two legs of the bridge and amplifier tubes in the other two legs. The left-hand portion of the bridge is identical to that appearing in Fig. 1 and the circuit portions have, accordingly, been assigned the same reference numerals. However, each of the bridge legs making up the right-hand side of the circuit is a voltage source comprising, in the particular embodiment illustrated, a secondary winding **120** of a transformer, a rectifier **121**, and a condenser **122**, connected as shown. For most purposes, primary windings **120***a*, corresponding to the secondary windings **120**, would constitute a single winding which may be connected to any suitable source of alternating current having fixed frequency and voltage. With a substantially constant voltage induced in the windings **120**, a substantially constant D. C. voltage will appear across the condensers **122**.

The operation of this circuit will be immediately apparent to those skilled in the art in view of the description of Figs. 2 and 3 appearing above. As the voltage of the grid **100** of the tube **71** is raised, the plate current through the tube **71** and hence through the biasing resistor **81** will increase. The increased negative bias of the grid **103** of the tube **72** caused by the increased current through the biasing resistor **81** reduces the current passing through the tube **72**. This increase of plate current in the tube **71** and the corresponding decrease of plate current in the tube **72** results, of course, in a current flowing through the load **89**.

Similarly, the signal S may reduce the plate current of the tube **71** in Fig. 3 below the value corresponding to balanced condition and the plate current of the tube **72** will increase by an equal amount. Current will then flow from right to left through load **89**.

The resistance value of the biasing resistor **81** in Fig. 4 may, of course, be made equal to the reciprocal of the transconductance of the tube **72**, as in the circuits of Figs. 2 and 3, to obtain linear operation over a maximum range. Also, the use of a resistor **81** having greater resistance than the value

$$\frac{1}{g_m}$$

of the tube **72** will result in greater sensitivity of the circuit, that is, a greater amplification factor, but results in a nonlinear output.

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, contemplated 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:

1. A direct current bridge circuit amplifier comprising four amplifier tubes, one each in the four legs of said bridge, the cathodes of the first and second tubes being connected together and the plates of the third and fourth said tubes being connected together, a direct current source of potential connected between the plates of said third and fourth tubes and the cathodes of said first and second tubes, the plate of said first tube being coupled to the cathode of said third tube and the plate of said second tube being coupled to said cathode of said fourth tube, a load connecting the cathodes of said third and fourth tubes, a voltage divider connected at one end

to the plate of said first tube and terminating at its other end at a point whose voltage is below that of the cathode of said first tube, a tap on said voltage divider connected to the grid of said second tube for controlling the voltage thereof, the position of said tap being selected whereby the voltage variations of said grid of said second tube are opposite to and equal in amount to the variations in the grid voltage of said first tube, means for varying the grid voltage of said third tube in accordance with an opposite linear function of the plate current of said first tube including a resistor arranged in the plate circuit of said first tube to carry the plate current thereof and an electrical connection between the grid of said third tube and the plate of said first tube, and means for varying the grid voltage of said fourth tube in accordance with an opposite linear function of said second tube including a resistor arranged in the plate circuit of said second tube to carry the plate current thereof and an electrical connection between the grid of said fourth tube and the plate of said second tube, said resistors each having a resistance value substantially equal to the reciprocal of the transconductance of the adjoining one of said third and fourth tubes.

2. A direct current bridge circuit amplifier comprising four amplifier tubes, one each in the four legs of said bridge, the cathodes of the first and second tubes being connected together and the plates of the third and fourth said tubes being connected together, a direct current source of potential connected between the plates of said third and fourth tubes and the cathodes of said first and second tubes, the plate of said first tube being coupled to the cathode of said third tube and the plate of said second tube being coupled to said cathode of said fourth tube, a load connecting the cathodes of said third and fourth tubes, a voltage divider connected at one end to the plate of said first tube and terminating at its other end at a point whose voltage is below that of the cathode of said first tube, a tap on said voltage divider connected to the grid of said second tube for controlling the voltage thereof, the position of said tap being selected whereby the voltage variations of said grid of said second tube are opposite to and equal in amount to the variations in the grid voltage of said first tube, means for varying the grid voltage of said third tube in accordance with an opposite linear function of the plate current of said first tube including a resistor arranged in the plate circuit of said first tube to carry the plate current thereof and an electrical connection between the grid of said third tube and the plate of said first tube, and means for varying the grid voltage of said fourth tube in accordance with an opposite linear function of said second tube including a resistor arranged in the plate circuit of said second tube to carry the plate current thereof and an electrical connection between the grid of said fourth tube and the plate of said second tube.

WILBERT PARISOE.

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