

[54] **CONTROLLABLE CURRENT SOURCE**

[75] Inventor: **Frederick Kiko**, Sheffield Village, Ohio

[73] Assignee: **Lorain Products Corporation**, Lorain, Ohio

[22] Filed: **Sept. 11, 1973**

[21] Appl. No.: **396,225**

Related U.S. Application Data

[62] Division of Ser. No. 301,968, Oct. 30, 1972, abandoned.

[52] U.S. Cl. **307/34, 323/4**

[51] Int. Cl. **G05f 1/10**

[58] Field of Search 323/1, 4, 16, 19; 330/69; 307/31, 32, 33, 34, 35

[56] **References Cited**

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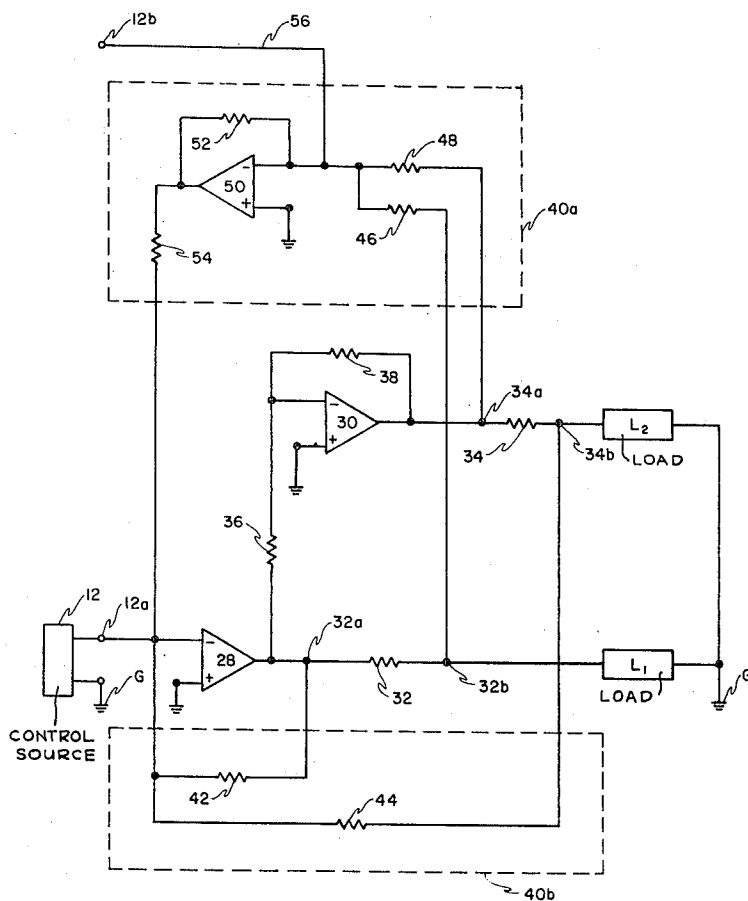
Primary Examiner—Robert K. Schaefer
Assistant Examiner—M. Ginsburg
Attorney, Agent, or Firm—Edward C. Jason

[57]

ABSTRACT

A circuit for providing a current the magnitude of which is determined by an externally generated control signal and which is substantially independent of the impedance of the load to which the current is applied. A current generating network generates an output current in accordance with the algebraic sum of the control signals applied to the inputs thereof. One of these inputs is energized by an externally generated control signal which sets the desired value of output current. A second of these inputs is controlled in accordance with a feedback signal indicative of the output current to assure that attempted deviations of the output current from the desired value are counteracted before they substantially affect the level of current through the load.

8 Claims, 3 Drawing Figures



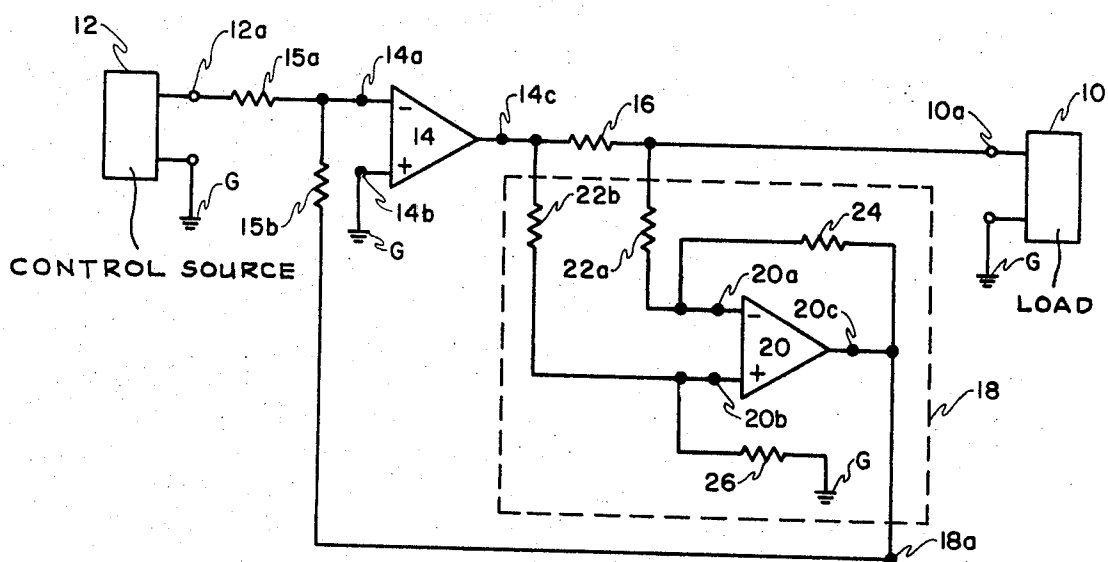


FIG. 1

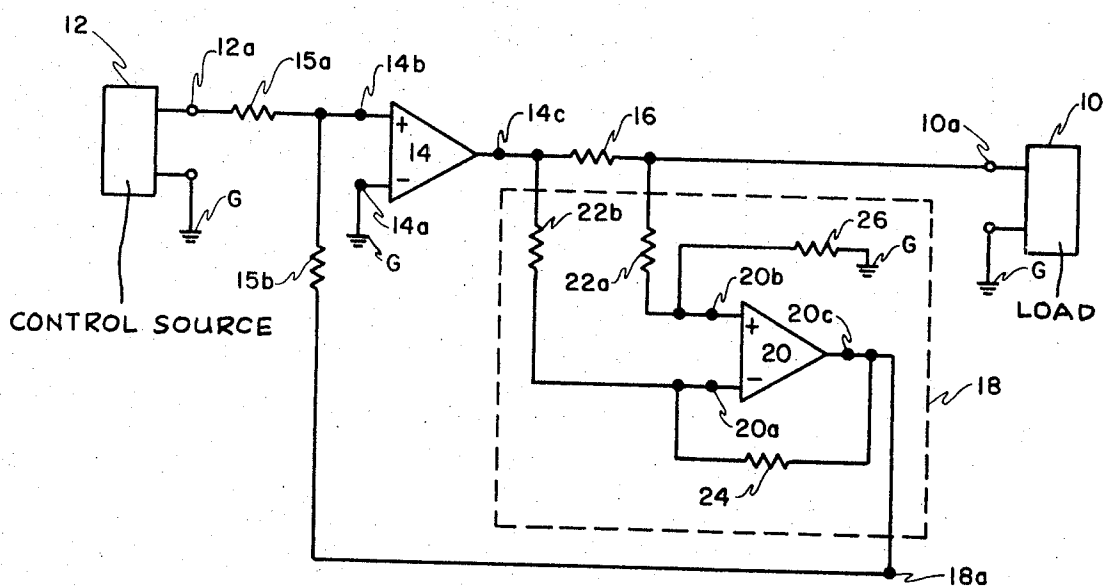


FIG. 2

CONTROLLABLE CURRENT SOURCE

This is a division of application Ser. No. 301,968, filed Oct. 30, 1972, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to current sources and is directed more particularly to current sources having an electronically controllable output current.

Current sources, that is, sources which produce currents the magnitudes of which are substantially independent of the input impedances of the circuits connected thereto, are utilized in a wide variety of electric and electronic control circuits. Current sources are, for example, used to supply bias currents which are substantially independent of temperature drift or induced voltages in the circuitry being biased. Current sources are also utilized to charge capacitors which must have a linearly increasing terminal voltage. Current sources have also been used to limit the amount of power which can be drawn from a source which drives a load that is subject to being short-circuited. Numerous other usages are familiar to those skilled in the art.

Presently available current sources commonly present one of two problems. On the one hand, current sources which are simple and inexpensive present the problem of providing an output current which is not sufficiently independent of changes in the impedance of the load connected thereto to be suitable for use in precise control system applications. On the other hand, current sources, heretofore known, which do produce a sufficiently constant output current are complex and expensive. In addition, current sources commonly present the further problem that the level of current provided thereby cannot be varied in any convenient manner with an externally generated control signal.

In accordance with the present invention, there is provided a current source which is simple and economical, which maintains the desired level of output current with a high degree of accuracy and which can be controlled in accordance with an externally generated control signal, as required, to change the magnitude of the output current.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an improved current source.

Another object of the invention is to provide an improved current source which accurately maintains the desired level of output current as the impedance of a load supplied therefrom varies over a wide range.

It is another object of the invention to provide a current source having a novel feedback network whereby the output current is maintained at the desired value in spite of changes in the impedance of a load connected thereto.

Still another object of the invention is to provide an improved current source of the above character wherein the output current can be controlled in accordance with an externally generated control signal. This allows the circuit of the invention to provide a time-varying output current having an instantaneous magnitude which is substantially independent of the impedance of the load connected thereto.

Yet another object of the invention is to provide an improved current source of the above character lending itself to either direct or inverse variation with

changes in the magnitude of an externally generated control signal.

It is another object of the invention to provide an improved current source which provides a first output current that varies directly with a control signal and a second output current that varies inversely with the same control signal.

It is still another object of the invention to provide an improved current source of the above character which may be energized by two control sources simultaneously to provide two equal and opposite output currents which vary in accordance with the difference between the control signals provided by the two different controls sources.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of one exemplary circuit embodying the invention,

FIG. 2 is a schematic diagram of another exemplary circuit embodying the invention, and

FIG. 3 is a schematic diagram of yet another circuit embodying the invention.

DESCRIPTION OF THE INVENTION

Referring to FIG. 1 there is shown a current source of the invention for energizing a load 10 with a current which varies substantially only in accordance with the magnitude of a control voltage or current provided by a control source 12. In the present illustrative embodiment, the circuit of the invention includes load current generating means which here takes the form of an operational amplifier 14 having an inverting input 14a, a non-inverting input 14b and an output 14c. This operational amplifier serves to generate and apply to load 10 a current having a magnitude which varies inversely in accordance with the algebraic sum of the signals that are applied to the input 14a thereof through resistors 15a and 15b. The circuit of the invention also includes current sampling means, which here takes the form of a resistor 16, for providing a voltage that varies directly in accordance with the current which amplifier 14 establishes through load 10. The circuit of the invention also includes a feedback network 18 for sensing the voltage established by current sampling resistor 16 and for controlling the feedback signal applied to amplifier input 14a, as required, to cause the current through load 10 to be substantially independent of the impedance thereof.

It will be understood that the terms "directly" and "non-inverting" are used herein to describe conditions in which a positive change in one voltage or current produces a positive change in another voltage or current. These terms are to be distinguished from the terms "inversely" and "inverting" which are used herein to describe conditions in which a positive change in one voltage or current produces a negative change in another voltage or current. It will be further understood that neither term requires that the magnitude of the change in one voltage or current is linearly related to the magnitude of the change in the other voltage or current.

To the end that feedback network 18 may generate a feedback signal suitable for application to amplifier 14, network 18 includes an operational amplifier 20 having an inverting input 20a, a noninverting input 20b and an output 20c. Feedback network 18 also includes amplifier input resistors 22a and 22b, a feedback resis-

tor 24 and an amplifier balancing resistor 26. This resistor-amplifier configuration produces, between network output 18a and ground G, a voltage which varies directly in accordance with the magnitude of the current flowing in the positive or rightward direction through current sampling resistor 16.

The operation of the circuit of the invention will now be described. Assuming that the voltage which control source 12 applies to circuit input terminal 12a and the current which flows out of circuit output terminal 10a are at the desired values, feedback network 18 applies to amplifier input 14a a feedback signal which is just sufficient to cause amplifier 14 to maintain the level of current flow through load 10 at the desired value. Under these conditions, the circuit of FIG. 1 is in a stable or quiescent state since no voltage or current exists which tends to change the existing conditions of the circuit.

If, under the above conditions, the resistance of load 10 should decrease, the current through sampling resistor 16 will increase. This increase in current, in turn, increases the positive voltage between feedback network output 18a and ground G and thereby increases the magnitude of the positive voltage at amplifier input 14a. Since a positive change in the voltage at amplifier input 14a causes a negative change in the voltage at amplifier output 14c, the above increase in the voltage at input 14a causes the output voltage of amplifier 14 to decrease and thereby restore the current through sampling resistor 16 and load 10 to its quiescent value.

If, on the other hand, the resistance of load 10 should increase, the current through resistor 16 will decrease. This decreases the positive feedback signal which network 18 applies to amplifier input 14a and thereby increases the output voltage of amplifier 14. The latter increase, in turn, restores the current through current sampling resistor 16 and load 10 to its quiescent value. Thus, departures in the current through resistor 16 from its quiescent value give rise to feedback signals which change the output voltage of amplifier 14, as required, to return the current through resistor 16 and load 10 to its quiescent value.

Because amplifier 14 is responsive to the algebraic sum of the signals applied to the input thereof, both the feedback signal provided by network 18 and the control voltages or currents applied through input resistors such as 15a determine the magnitude of the current through sampling resistor 16 and load 10. Since, as previously described, the feedback signal of network 18 serves to maintain the output current at its quiescent value, control of the quiescent value itself must be determined by the applied control voltages or currents. Accordingly, if the voltage or current of source 12 is constant, the magnitude of the current flow through sampling resistor 16 and load 10 will be constant, and, if the voltage or current of source 12 varies with time, the quiescent current through sampling resistor 16 and load 10 will vary in a similar fashion with time. Under the latter conditions, network 18 will vary the feedback signals, as required, to maintain the output current at the value determined by source 12, in spite of variations in the impedance of load 10. Thus, whether the current through sampling resistor 16 and load 10 is constant or time-varying, the circuit of the invention acts as a current source, that is, provides an output current which is substantially independent of the impedance of the load applied thereto.

Because the control signal established by control source 12 is applied to the inverting input of amplifier 14, a positive change in the voltage between circuit input terminal 12a and ground G causes a negative change in the magnitude of the current flowing to the right out of circuit output terminal 10a. Similarly, a negative change in the voltage between circuit input 12a and ground G causes a positive change in the current flowing to the right out of circuit output 10a. Thus, the circuit of FIG. 1 comprises an inverting type current source.

If it is desirable to produce a current source wherein the current at circuit output 10a varies directly rather than inversely with the control signal at circuit input 12a, this may be accomplished by utilizing the circuit of FIG. 2 which is similar to the circuit of FIG. 1, like parts being similarly numbered.

The circuit of FIG. 2 differs from the circuit of FIG. 1 in that the inverting and non-inverting inputs of operational amplifier 14 and operational amplifier 20 are interchanged. The interchange of these amplifier inputs does not alter the previously described current regulating characteristic since the effect of a feedback signal which varies inversely with output current has the same effect on the non-inverting input of an operational amplifier as has a feedback signal which varies directly with output current on the inverting input of an operational amplifier. Thus, the operation of the circuit of FIG. 2 is identical to the operation of the circuit of FIG. 1, except that the output current of the circuit of FIG. 2 varies directly with the voltage of source 12 while the output current of the circuit of FIG. 1 varies inversely with that voltage.

Under circumstances where it is necessary for a current source to supply current to a balanced load as, for example, a two-wire transmission line, it is desirable to energize the latter with a current source having two balanced current outputs, that is, a current source which provides two equal but opposite output currents. One form of the invention which is suitable for providing such balanced output currents is shown in the circuit of FIG. 3.

Referring to FIG. 3, there is shown first or negative load current generating means which here takes the form of an operational amplifier 28 and second or positive load current generating means which here takes the form of an operational amplifier 30. Amplifier 28 energizes a first load L1 with a current which varies inversely with the voltage of control source 12. Similarly, amplifier 30 energizes a second load L2 with a current which varies directly with the voltage of control source 12. These currents are supplied to loads L1 and L2 through respective current sampling resistors 32 and 34.

To the end that the negative and positive load current supplied by amplifiers 28 and 30, respectively, may be of equal amplitude, amplifier 30 is provided with input and feedback resistors 36 and 38, respectively, these resistors being so proportioned that the output voltage of amplifier 30 is equal in amplitude to the output voltage of amplifier 28. In addition, input resistor 36 is connected to the output of amplifier 28 and to the inverting input of amplifier 30 to assure that the output voltages of amplifiers 28 and 30 have opposite signs. Accordingly, it will be seen that the output voltages of amplifiers 28 and 30 are equal in amplitude and opposite in sign. It will be understood that the equal and oppo-

site voltages generated by separate amplifiers 28 and 30 may also be generated by a single operational amplifier of the type which generates two complementary output voltages.

In order that the currents in balanced loads L1 and L2 may be determined by control source 12 and not by the impedances of loads L1 and L2, there is provided a feedback network including a first component feedback network 40a and a second component feedback network 40b. These networks energize the inverting input of amplifier 28 with a plurality of feedback currents which add together to provide a net feedback signal that is proportional to the sum of the current through current sampling resistors 32 and 34. Resistors 42 and 44 of feedback network 40b, for example, energize the input of amplifier 28 with feedback currents that vary with the potentials with respect to ground of sampling resistor terminals 32a and 34b, respectively. Similarly, resistors 46 and 48 of feedback network 40a serve to couple to the input of amplifier 28 feedback currents that vary with the potentials with respect to ground of sampling resistor terminals 32b and 34a.

To the end that the net feedback current applied to the input of amplifier 28 may vary with the sum of the load currents through sampling resistors 32 and 34, resistors 45 and 48 are connected to amplifier 28 through an amplifier 50 which inverts the phase of the feedback currents through resistors 46 and 48. This inversion assures that only the difference between the sum of the currents in feedback resistor 42-44 and the sum of the currents in feedback resistors 46-48 is effective in controlling amplifier 28. It will be understood that for the difference between the above feedback currents to accurately reflect the sum of the currents through resistors 32 and 34, resistors 52 and 54 must have values such that the common components of the voltages at terminal pairs 32a-32b and 34a-34b substantially cancel one another under no load conditions.

Assuming that the above described resistance values are substantially as described, feedback networks 40a and 40b will operate in the manner described in connection with the circuits of FIGS. 1 and 2 to render the currents through loads L1 and L2 substantially independent of the impedance thereof. That is, the feedback network comprising component feedback networks 40a and 40b provides amplifiers 28 and 30 with a feedback signal which opposes any attempt of the current through loads L1 and L2 to deviate from the value set by control source 12.

As previously described, the circuit of FIG. 3 generates in load L1 a current which varies inversely with the voltage of source 12 and in load L2 a current which varies directly with the voltage of source 12. If it is desirable to on occasion reverse the phase relationship between the currents in loads L1 and L2 and the voltage of source 12, this may be accomplished by switching control source 12 from contact with input terminal 12a and into contact with an alternative or phase-reversing input terminal 12b. This is because the latter terminal allows control source 12 to energize the input of amplifier 28 through a conductor 56 and inverting amplifier 50 and thus effectively reverse the phase of the control signal before it is introduced into the current control circuitry of FIG. 3. Thus, the application of a control signal to input 12b causes the current in load L1 to vary directly with the control signal and causes the current in load L2 to vary inversely with the control signal.

In addition to serving as alternative inputs to the current source of FIG. 3, inputs 12a and 12b may be energized simultaneously from separate control sources. In the latter event, it will be understood that the currents in load L1 and L2 will vary with the difference between the control signals applied to inputs 12a and 12b. Thus, the circuit of FIG. 3 is suitable for use as a current source having equal and opposite outputs and having a differential input.

In view of the foregoing it will be seen that a current source constructed in accordance with the present invention is adapted to provide an output current which varies in accordance with an externally generated control signal and is adapted to maintain that current at the desired value substantially without regard to the impedance of the load to which the current is applied. Furthermore, the circuit of the invention is readily adaptable to forms in which this variation is either direct or inverse or both direct and inverse.

It will be understood that the above described embodiments are for descriptive purposes only and may be changed or modified without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In a circuit for generating two currents which are substantially equal and opposite and which have magnitudes that are substantially independent of the impedance of the circuitry to which the currents are applied, the combination of, a circuit input, first and second circuit outputs, first and second current generating means each having inverting input means and output means, first and second current sampling means for generating respective signals which vary in accordance with the currents at respective circuit outputs, means for connecting the input means of said first generating means to said circuit input, means for connecting said first sampling means between the output means of said first generating means and said first circuit output, means for connecting the input means of said second generating means to the output means of said first generating means, means for connecting said second sampling means between the output means of said second generating means and said second circuit output, feedback means for energizing the input means of said first generating means with a feedback signal indicative of the current through both said first and said second sampling means and means for connecting said feedback means to said first and second sampling means and to the input means of said first generating means.

2. A circuit as set forth in claim 1 including a phase-reversing circuit input, inverting means having input means and output means, said inverting means serving as means for generating a signal at the output means thereof which is substantially equal and opposite to the signal at the input means thereof, and means for connecting said inverting means between said phase-reversing circuit input and the input means of said first current generating means.

3. In a circuit for generating two currents which are substantially equal and opposite and which have magnitudes that are substantially independent of the impedance of the circuitry to which the currents are applied, the combination of, first and second circuit inputs, first and second circuit outputs, current generating means having input means and first and second output means, said current generating means serving as means for establishing substantially equal and opposite voltages at

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the output means thereof in accordance with the voltage at the input means thereof, first and second current sampling means, means for connecting said current sampling means between respective output means of said current generating means and respective circuit outputs, means for connecting the input means of said current generating means to said first and second circuit inputs, feedback means for energizing the input means of said current generating means in accordance with the current through both said first and said second current sampling means and means for connecting said feedback means to said sampling means and to the input means of said generating means.

4. A circuit as set forth in claim 3 in which the means for connecting the input means of said generating means to said first and second circuit inputs includes a connector for connecting the input means of said generating means to said first circuit input and inverting means for connecting the input means of said generating means to said second circuit input.

5. A circuit as set forth in claim 3 in which said feedback means includes first, component feedback means for providing an inverted feedback signal and second, component feedback means for providing a non-inverted feedback signal.

6. In a circuit for generating two currents which are substantially equal and opposite and which have magnitudes that are substantially independent of the impedance of the circuitry to which the currents are applied, the combination of, a circuit input, first and second circuit outputs, current generating means having input means and first and second output means, said current generating means serving as means for establishing substantially equal and opposite voltages at said first and second output means in accordance with the voltage at

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the input means thereof, first and second current sampling means, means for connecting said first and second current sampling means in current sensing relationship between respective output means of said current generating means and respective circuit outputs, means for connecting the input means of said current generating means to said circuit input, feedback means for energizing the input means of said current generating means in accordance with the currents sensed by both of said current sampling means and means for connecting said feedback means to said sampling means and to the input means of said current generating means.

7. A circuit as set forth in claim 6 in which said feedback means includes first, second, third and fourth resistance means, and in which said means for connecting said feedback means to said current sampling means and to the input means of said current generating means includes means for connecting said first resistance means to a first end of said first current sampling means and to the input means of said generating means, means for connecting said second resistance means to a second end of said second current sampling means and to the input means of said generating means, means for connecting said third resistance means to a second end of said first current sampling means and to the input means of said generating means and means for connecting said fourth resistance means to a first end of said second current sampling means and to the input means of said generating means.

8. A circuit as set forth in claim 7 in which said connecting means for said third and fourth resistance means includes inverting means for inverting the phase of the feedback signals applied to said generating means through said third and fourth resistance means.

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