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J. W. HAAGEN-SMIT ETAL
CONSTANT CURRENT POWER SUPPLY

3,370,222

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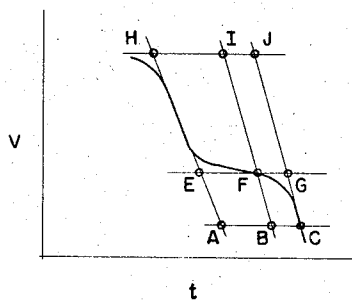


FIG. 1

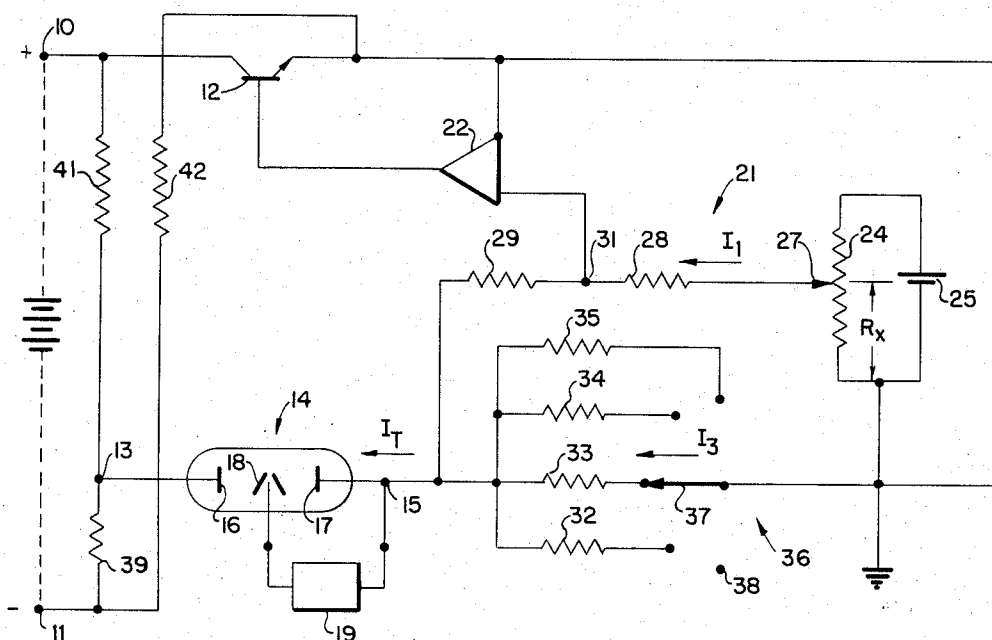


FIG. 2

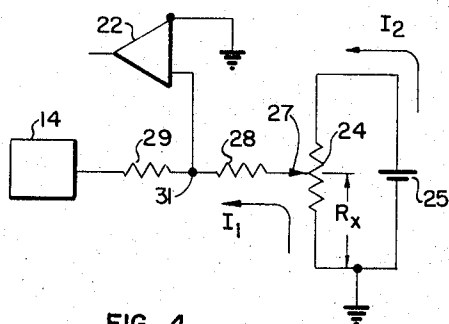


FIG. 4

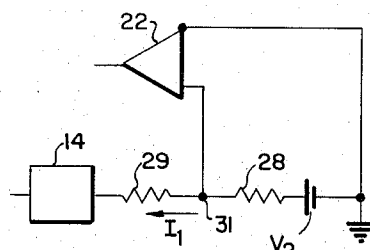


FIG. 3

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CONSTANT CURRENT POWER SUPPLY

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12 Claims. (Cl. 323-4)

ABSTRACT OF THE DISCLOSURE

A constant current power supply is disclosed which may be accurately and continuously adjustable over a wide range of output current values. The constant current power supply has a variable impedance element and a load current sensing circuit connected in series with a load and a suitable source of current. The sensing circuit consists of two parallel branches, one branch providing for the selection of one of a plurality of constant impedances (including an infinite impedance or a open circuit) and the other a variable potential source and an impedance connected in series such that the potential drop across the impedance due to load current is in opposition to the variable potential source. The variable potential source provides for continuously varying the current over the entire range of current, the range being determined by the value of the selected impedance in the other branch. A feedback senses the difference in the aforementioned potentials and controls the impedance of the variable impedance element to maintain these potentials equal, thereby maintaining the current through the load constant.

This invention relates generally to constant current power supplies and more particularly to a constant current power supply which is accurately and continuously adjustable over a wide range of output current values.

In the field of chronopotentiography it is the general practice to provide a constant current between an auxiliary electrode and a working electrode that are immersed in a test solution and to monitor the potential between a third electrode, commonly referred to as the reference electrode, and the working electrode. By monitoring the potential between these electrodes as a function of time, information concerning the quality and quantity of electrolytically active constituents of the test solution may be determined.

FIG. 1 illustrates a typical chronopotentiogram obtained when passing an electrolytic current of 100 μ a. through a solution of potassium ferrocyanide and potassium chloride. After the graph is obtained lines AH and CJ are drawn tangential to the curve and lines HJ and AC are arbitrarily chosen horizontal lines. Point F on the potentiogram is established by drawing line IB such that

$$IH=1/4HJ$$

and

$$BC=1/4AC$$

Line EG is then drawn parallel to lines HJ and AC through point F and the limits EG define the transition time.

The transition time may be related to the concentration of an ion in solution according to the following equation:

$$T=\left(\frac{kC}{i}\right)^2 \quad (1)$$

where T is in seconds, k is a constant, i is the electrolytic current and C is the concentration. It may readily be seen that the accuracy of the determination is depend-

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ent upon the degree to which the electrolytic current may be maintained constant. It is also apparent that the accuracy of the measurement is directly proportional to the accuracy to which the electrolytic current is known.

From the chronopotentiogram of FIG. 1 it is obvious that the impedance of the solution undergoes a large change during the test period. Thus the power supply must be capable of maintaining a constant current over a wide range of load impedances. It is further apparent from Equation 1 that the transition time is a direct function of the concentration of the test solution. In order to perform the measurement within a reasonable time at high concentrations it is desirable to provide a power supply capable of supplying a constant current over a wide range of current values.

Standard methods of current measurement, such as, for example, meters and electronic or manually balanced meters, are either not sufficiently accurate, prohibitively expensive or inconvenient to operate. Trial and error adjustments of electrolytic current may be either by changing voltage potential or varying a series resistance; however, each of these methods requires accurate and continuous readout of the actual current flowing through the electrode system.

Prior art constant current power supplies have provided either continuously adjustable current values over an extremely limited range at low current values or non-adjustable selected currents over a wide range of current values. The prior art has not heretofore provided a constant current power supply that has been continuously variable over a wide range of output current values.

It is, therefore, an object of the present invention to provide a constant current power supply which provides a constant output current which is accurately and continuously adjustable over a wide range of current values.

Another object is to provide a constant current power supply wherein the output current may be accurately and continuously adjusted over a plurality of selected ranges of output current values.

A further object is to provide a constant current power supply which allows the setting of a calibrated dial to a desired current value which is delivered to the load quickly and accurately without regard for the load impedance.

A still further object is to provide a constant current power supply that allows setting of a calibrated dial to a value of desired load current which is continuously adjustable over a wide range of current values without regard for the load impedance which is inexpensive of construction, accurate in regulation and convenient in operation.

Yet another object is to provide a constant current power supply wherein the output current may be accurately and continuously adjusted over a dynamic range of ten million to one.

Other objects and many of the attendant advantages of this invention will become readily apparent to those skilled in the art as the same becomes better understood from the following description when considered in connection with the accompanying drawing wherein:

FIG. 1 illustrates a typical chronopotentiogram indicating the electrode potential as a function of time during the transition period;

FIG. 2 illustrates an electrical schematic diagram of the basic components of a constant current power supply constructed after the teachings of this invention; and

FIGS. 3 and 4 are simplified schematics of the sensing circuit of the power supply of FIG. 2 utilized to illustrate the operating principles of the embodiment of FIG. 2.

Referring now to FIG. 2, input terminals 10 and 11

are connected across any suitable source of direct current potential having the polarity indicated. A variable impedance device 12, such as, for example, an NPN transistor, is connected in electrical series circuit between input terminal 10 and output terminal 15. Load impedance 14 is connected between output terminals 13 and 15. The load may be of any type requiring a constant current even though the impedance thereof varies and is here illustrated as the auxiliary and working electrodes 16 and 17, respectively, of a chronopotentiometer. The potential of working electrode 17 with respect to a reference electrode 18 is monitored by any suitable device, such as, for example, recorder 19.

Connected between the output electrode of variable impedance element 12 and output terminal 15 is a sensing circuit 21. The output of the sensing circuit is connected to one terminal of a three terminal amplifier 22 having its output connected to control the impedance of variable impedance element 12. Amplifier 22 may conveniently comprise a DC amplifier having a high frequency response so as to respond to load changes within $\frac{1}{1000}$ second and a high input impedance. Amplifier 22 amplifies the error signal at its input and applies the amplified voltage difference, without phase inversion, to the control element of variable impedance 12 to control the impedance such that the proper current flows to maintain the error signal at the input of amplifier 22 at substantially zero.

The sensing circuit 21 comprises a potentiometer 24 connected across any suitable source of potential 25 here illustrated as a battery. In the embodiment illustrated the negative terminal of the potential source is connected to the output electrode of variable impedance element 12 which may conveniently comprise circuit ground. Slider 27 of potentiometer 24 is connected through resistors 28 and 29 to output terminal 15. Junction 31 between resistors 28 and 29 comprises the output terminal of the sensing circuit and is connected to the input terminal of amplifier 22. Resistors 32, 33, 34 and 35 each have one end thereof connected to output terminal 15 and the other to respective fixed contacts of any suitable range selection switch 36. Selector arm 37 of switch 36 is connected to the output electrode of variable impedance element 12. Switch 36 has one fixed contact 38 which is unconnected. Output terminal 13 is connected through resistor 39 to input terminal 11.

It is apparent that the sensing circuit comprises first and second branches connected in parallel and the entire load current flows through these branches. The first branch of the sensing circuit includes a portion of potentiometer 24 between circuit ground and slider 27 which is indicated on the drawing as R_x in series with resistors 28 and 29. If amplifier 22 has sufficiently high input impedance and high gain the amount of current drawn from terminal 31 will be substantially zero. Thus, the current flowing through resistance 28 is equal to the current flowing through resistance 29. The second branch of the sensing circuit includes the plurality of fixed resistors and switch 36 such that one of these resistors may be selected and placed in parallel with the first branch. In this instance it is apparent that the load current divides between the first and second branches and when selector arm 37 is positioned to engage terminal 38 the impedance of the second branch is infinite and all of the load current flows through the first branch.

For a clearer understanding of the operation of the sensing circuit reference is made to the schematic of FIG. 3 wherein the second branch is omitted, i.e., the impedance is infinite and variable potentiometer 24 has been replaced by potential source V_2 . If the current through load 14 is I_1 and amplifier 22 draws negligible current, then the current through resistance 28 is also I_1 . Further, if amplifier 22 has sufficiently high gain it will operate in such a manner so as to maintain the error voltage at its input at substantially zero. Thus the potential

at junction 31 is maintained at substantially zero by amplifier 22 and, therefore,

$$V_2 - I_1 R_{28} = 0 \quad (2)$$

and

$$I_1 = \frac{V_2}{R_{28}} \quad (3)$$

If battery V_2 has an internal impedance impedance R_2 then:

$$V_2 - I_1 (R_{28} + R_2) = 0 \quad (4)$$

and

$$I_1 = \frac{V_2}{R_{28} + R_2} \quad (5)$$

In the preferred embodiment of the invention, the internal resistance R_2 of source 25 is made so small compared to the resistance of R_{28} that it may be neglected. Since the value of R_{28} is fixed it is apparent from Equation 5 that the load current I_1 , is a direct function of V_2 . By varying the value of V_2 the load current may be varied.

In the preferred embodiment of the invention as illustrated in FIG. 2, in order to obtain a continuously variable load current, voltage source V_2 comprises potentiometer 24 having a total impedance which is low compared to the resistance of resistor 28.

Consider now the operation of the sensing circuit of FIG. 2 with selector arm 37 of switch 36 engaging unconnected contact 38. The equivalent circuit is illustrated in FIG. 4. Let I_2 be the current flowing through potentiometer 24 as a result of potential source 25. Then the potential at slider 27, which represents source V_2 of FIG. 3 is:

$$V_2 = I_2 R_x = E_{25} \cdot \frac{R_x}{R_{24}} \quad (6)$$

where $0 \leq R_x \leq R_{24}$ and E_{25} is the potential of source 25. It is apparent that when R_x is zero that V_2 is zero and when R_x equals R_{24} that V_2 equals the potential of source 25. It is also apparent that the value of V_2 may be continuously varied from zero to the potential of source 25.

If amplifier 22 draws negligible current from point 31 and operates to maintain the error signal at its input at substantially zero, then the potential at junction 31 is substantially zero and all of the load current I_1 flows through potentiometer 24 and resistor 28. Therefore:

$$V_2 - I_1 \left[R_{28} + R_x \left(1 - \frac{R_x}{R_{24}} \right) \right] = 0 \quad (7)$$

and

$$I_1 = \frac{V_2}{R_{28} + R_x \left(1 - \frac{R_x}{R_{24}} \right)} \quad (8)$$

If the impedance of potentiometer 24 is made small compared to resistance 28 it may be neglected. Substituting zero for R_x in Equation 8 and substituting Equation 6 in Equation 8 we have:

$$I_1 = E_{25} \cdot \frac{R_x}{R_{24}} \cdot \frac{1}{R_{28}} \quad (9)$$

If E_{25} is constant then:

$$I_1 = k R_x \quad (10)$$

where $0 \leq R_x \leq R_{24}$.

It is apparent from Equation 10 that the load current is continuously variable from zero to some maximum value and is a linear function of the position of slider 27. Thus by appropriately calibrating potentiometer 24, any value of load current within the maximum value may be quickly and accurately selected. The circuit of FIG. 4 is only suitable at low current levels, when high accuracy is required. At higher currents the value of $I_1 R_x$ becomes

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large and, therefore, the value of R_x relative to R_{28} cannot be neglected. If R_x is not neglected the load current is:

$$I_1 = kR_x \cdot \frac{1}{R_{28} + R_x \left(1 - \frac{R_x}{R_{24}}\right)} \quad (11)$$

and it is apparent that, due to loading errors of potentiometer 24, the current is no longer a linear function of the slider position.

The difficulties in extending the range of current which can be supplied by the power supply of the instant invention while maintaining accurate linearity and ease of operation are simply and economically overcome by the addition of a range selection switch 36 which adds in parallel to the first branch of the sensing circuit a second branch comprising fixed resistors 32-35 as illustrated in the embodiment of FIG. 2.

Let I_3 be the current flowing through the second branch, I_1 be the current flowing through the first branch, and R_y be the value of one of resistors 32-35.

If the potential at junction 31 is maintained at substantially zero then Equations 2 through 10 are valid for the circuit of FIG. 2. With range selector switch 36 contacting one of the resistors in the second branch as illustrated, from Kirchhoff's voltage law we have:

$$I_3 R_y - I_1 R_{29} - I_1 R_{28} + V_2 - I_1 \left[R_x \left(1 - \frac{R_x}{R_{24}}\right) \right] = 0 \quad (12)$$

Since from Equation 7,

$$V_2 - I_1 \left[R_{28} + R_x \left(1 - \frac{R_x}{R_{24}}\right) \right] = 0$$

we have:

$$I_3 R_y - I_1 R_{29} = 0 \quad (13)$$

If I_t is the total load current, then

$$I_t = I_1 + I_3 \quad (14)$$

and if Equation 13 is solved for I_3 and substituted in Equation 14, we have

$$I_t = I_1 \left(\frac{R_{29}}{R_y} + 1 \right) \quad (15)$$

From Equation 15 it can be seen that if R_y is infinite, as is the case when selector arm 37 of range selector switch 36 contacts fixed contact 38, that $I_t = I_1$ which is the case of FIGS. 3 and 4. When R_y is not infinite the voltage drop across this branch is equalled by the voltage dropped across resistor R_{29} as may be seen from Equation 13 which allows terminal 31 to be maintained at zero potential.

It should be noted that the value of I_1 depends only upon the magnitude of R_{28} , R_x and V_2 and, therefore, if the impedance of potentiometer 24 is made small compared to resistance 28 then Equation 10 remains valid and the linear adjustment of the current by means of potentiometer 24 is not affected by the presence of range selection resistors 32, 33, 34 or 35. Substituting Equation 10 in Equation 15 yields:

$$I_t = kR_x \left(\frac{R_{29}}{R_y} + 1 \right) \quad (16)$$

The net effect is that the maximum value of I_1 for all ranges is the same and only the load current increases by an amount dependent upon the factor

$$\left(\frac{R_{29}}{R_y} + 1 \right)$$

The maximum value of I_1 is chosen to be compatible with required accuracy, i.e., the $I_1 R_x$ voltage drop may be neglected.

Consider now the operation of the embodiment of FIG. 2. Let it be presumed that selector arm 37 of range selector switch 36 engages contact 38 and slider 27 posi-

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tioned along potentiometer 24 until the desired current passes load 14. Assume now that the impedance of load 14 decreases thus tending to increase the current I_1 flowing to the first branch of the sensing circuit. An increase in load current through resistors R_x and 28 creates a negative going signal at junction 31 with respect to circuit ground. Since amplifier 22 has no phase inversion a negative going signal appears at its output increasing the impedance of transistor 12 to reduce the current until the potential at junction 31 is again substantially zero.

Assume now that selector arm 37 is switched to resistor 32. The load current divides, by means of R_{29} , between the parallel branches thus decreasing the current I_1 and a positive going signal is applied at the input of amplifier 22. The output of the amplifier tends to decrease the impedance of transistor 12 until I_1 is again restored to its original value. Thus the load current is increased by a factor I_1

$$\left(\frac{R_{29}}{R_y} + 1 \right)$$

without a resultant increase in current flow through the first branch of the sensing circuit. It is apparent that by shifting the position of slider 27 the load current may be continuously controlled from zero to a maximum value which is determined by range selection switch 36.

In an actual preferred embodiment of the invention constructed in accordance with the schematic illustrated in FIG. 2, the following values were utilized:

I_1 max. = 10 μ a.	R_{32} = 11,110
R_{24} = 500	R_{33} = 1010
R_{28} = 500 K.	R_{34} = 100.1
R_{29} = 100 K.	R_{35} = 10.01
E_{25} = 5 v.	

An amplifier having a gain of approximately 100,000 was utilized and variable impedance element 12 was a 2N2196 transistor. With the values as indicated a constant current power supply was provided having output ranges of 0-10, 0-100, 0-1000 μ a; and 0-10, 0-100 ma. over the range of 0-25 volts with an overall accuracy of 0.2%. Regulation was 0.002% as the load changed from 15 ohm to 220 K. ohms at 100 μ a. of current. The foregoing accuracy was within the tolerances of the components utilized and should ultimately depend only upon these tolerances and the gain of the amplifier. The ultimate limiting factor would appear to be the stability of the source utilized as battery 25. It is apparent that the embodiment constructed provides a continuously variable constant current range from 0.01 μ a. to 100 ma., a dynamic range of $10^6:1$.

In order to regulate the output current through the load to zero the leakage current through variable impedance 12 must be compensated. This has been accomplished by arranging the variable impedance 12 in a bridge circuit across source terminals 10 and 11. Resistors 39 and 41 comprise one branch of the bridge and variable impedance element 12 and resistor 42 comprise the other branch. The load is taken between the junction of resistors 39 and 41 and the junction of variable impedance element 12 and resistor 42.

Consider the circuit of FIG. 2 when output terminals 13 and 15 are open circuited. When variable impedance 12 is at a maximum value a small leakage current will flow through variable impedance 12 and resistor 42 developing a potential at output terminal 15. It is clear that if output terminal 13 is held at a potential equal to or higher than the potential at terminal 15 when impedance 12 is a maximum there will always be a value of impedance 12 at which the potential across the load is zero and thus no load current will flow.

Resistors 41 and 39 are utilized to develop the required potential at terminal 13. Resistor 39 is chosen to be small compared to the value of load 14. Resistors 41 and 42

are preferably large compared to load 14 to reduce excessive current drain from terminals 10 and 11.

While the invention has been described in detail in connection with the preferred embodiment of FIG. 2 and in connection with a chronopotentiometer it is apparent that the constant current power supply constructed after the teaching of this invention may be utilized with any type of load requiring a constant current such as the calibration and testing of instruments, meters, semiconductors and in the coulometric generation of chemical reagents and the like. It is also apparent that an NPN transistor or other suitable variable impedance elements may be utilized by appropriate circuit changes. The specific embodiment illustrated in FIG. 2 and the values of components indicated herein are given by way of example only of a single preferred embodiment and not by way of limitation and it is apparent to those skilled in the art that variations and modifications may be made therein without departing from the spirit and scope of the invention as set forth in the appended claims.

We claim:

1. A current regulating device for controlling current flow through a load over a wide range of current values comprising:

variable impedance means and a sensing circuit adapted to be connected in electrical series circuit with a source and a load, said sensing means connected to said variable impedance means to vary the impedance thereof to maintain load current at a preselected value;

said sensing means including first circuit means adapted to be connected in series circuit with said load for selecting one of a plurality of current ranges and second circuit means connected in parallel with said first circuit means for continuously varying said preselected value over each of said ranges.

2. A current regulating device for controlling current flow through a load over a wide range of values comprising:

variable impedance means adapted to be connected in series circuit with a source and a load for controlling current through said load;

a first current path connected in series circuit with said variable impedance means, said first current path including a variable potential source and first and second impedance means in series, the potential drop across said first impedance means due to load current being in opposition to the potential of said variable potential source;

a plurality of impedance means; means for selecting one of said plurality of impedance means and connecting said one impedance means electrically in parallel with said first current path; means connected between said first current path and said variable impedance means for sensing said opposing potentials and controlling the impedance of said variable impedance means to maintain said potentials substantially equal.

3. A current regulating device for controlling current flow through a load over a wide range of values comprising:

a potentiometer having a slider; a potential source connected across said potentiometer; first and second impedance means connected in series circuit to said slider;

one end of said potentiometer, said slider and said first and second impedance means adapted to be connected in series circuit with a load to form a first current path, the potential drop between said one end of said potentiometer and said slider due to said potential source being in opposition to the potential drop across said first impedance means due to load current;

a plurality of impedance means; means for selecting one of said plurality of impedance

means and connecting said one impedance means in parallel with said first current path;

control means connected to said first current path for controlling load current in response to changes in said opposing potentials, said control means including variable impedance means adapted to be connected in series circuit with a source and a load.

4. A current regulating device for controlling current flow through a load over a range of several decades comprising:

a potentiometer having a slider;

a potential source connected across said potentiometer;

one end of said potentiometer, said slider and first and second impedance means connected in series in a first current path;

a plurality of impedance means and means for selecting one of said plurality of impedance means connected in a second current path in parallel with said first current path;

said first and second paths connected in series with a load so as to pass load current, the potential drop across said potentiometer due to said potential source being in opposition to the potential drop across said first impedance means due to load current and the impedance of said potentiometer being negligible compared to the impedance of said first impedance means; and

control means connected to said first current path for controlling load current in response to changes in said opposing potentials, said control means including variable impedance means adapted to be connected in series circuit with a source and a load.

5. A current regulating device for controlling current flow through a load over a wide range of current values comprising:

at least one input terminal;

at least one output terminal;

current control means connected to control the current between said input and output terminals to provide a controlled load current;

current sensing means connected between said input and output terminals in series with said current control means for sensing said load current, said current sensing means including means for selecting one of a plurality of maximum load currents and means for continuously varying said load current from substantially zero to said selected maximum to provide a desired load current, said current sensing means producing an error signal proportional to the deviation of said load current from said desired load current; and

means interconnecting said current control means and said current sensing means for controlling the current through said current control means in response to said error signal.

6. A current regulating device for controlling load current over a wide range of current values comprising:

at least one input terminal;

at least one output terminal;

current control means connected to control the current between said input and output terminals to provide a controlled load current;

current sensing means connected between said input and output terminals in series with said current control means for sensing said load current, said current sensing means including means for selecting one of a plurality of maximum load currents and means for continuously varying said load current from substantially zero to said selected maximum to provide a desired load current, the current through said last named means having a common maximum value for all of said plurality of maximum load currents, said current sensing means producing an

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error signal proportional to the deviation of said load current from said desired load current; and means interconnecting said current control means and said current sensing means for controlling the current through said current control means in response to said error signal to maintain said error signal at substantially zero.

7. A current regulating device for controlling load current over a wide range of current values comprising: at least one input terminal;

at least one output terminal;

current control means connected to control the current between said input and output terminals to provide a controlled load current;

current sensing means connected between said input and output terminals for sensing said load current, said current sensing means including first and second parallel connected branches, said first branch including means for selecting one of a plurality of maximum load currents, said second branch including means for continuously varying said load current from substantially zero to said selected maximum to provide a desired load current, the current passing said second branch having a common maximum value for all of said plurality of maximum load currents, said current sensing means producing an error signal proportional to the deviation of said load current from said desired load current; and

means interconnecting said current control means and said current sensing means for controlling the current through said current control means in response to said error signal to maintain said error signal at substantially zero.

8. A current regulating device for controlling current flow through a load over a wide range of current values comprising:

at least one input terminal;

at least one output terminal;

current control means connected to control the current between said input and output terminals to provide a controlled load current;

current sensing means connected to said input and output terminals for sensing said load current, said current sensing means including first and second parallel branches, said first branch including means for selecting one of a plurality of maximum load currents, said second branch including a source of variable potential, said current sensing means producing an error signal proportional to the deviation of said load current from a desired load current determined by said source of variable potential; and means interconnecting said current control means and said current sensing means for controlling the current through said current control means in response to said error signal to maintain said error signal at substantially zero.

9. A current regulating device for controlling current flow through a load over a wide range of current values comprising:

at least one input terminal;

at least one output terminal;

current control means connected to control the current between said input and output terminals to provide a controlled load current;

current sensing means connected between said input and output terminals to sense said load current, said current sensing means including first and second parallel connected branches, said first branch including means for selecting one of a plurality of maximum load currents, said second branch including a source of variable potential continuously varied from substantially zero to a maximum value and an impedance connected in series with said source of variable potential, said variable potential connected to oppose the voltage drop due to a

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portion of said load current flowing through said impedance thereby producing an error signal proportional to the deviation of said load current from a desired value; and

means interconnecting said current sensing means and said current control means to control the current through said current control means in response to said error signal to maintain said error signal at substantially zero.

10. A current regulating device for controlling current flow through a load over a wide range of current values comprising:

at least one input terminal;

at least one output terminal;

current control means connected to control the current between said input and output terminals to provide a controlled load current;

current sensing means including first and second parallel branches connected in series circuit with said current control means between said input and output terminals so as to pass said load current, said first branch including a plurality of selectable impedance means for selecting one of a plurality of maximum load currents, said second branch including a source of variable potential and an impedance means, said source of potential being continuously variable from zero to a maximum value and connected to oppose the voltage drop across said impedance due to a portion of said load current flowing through said impedance thereby providing an error signal proportional to the deviation of said load current from a desired value determined by said source of variable potential; and

means interconnecting said current control means and said current sensing means to control the current through said current control means in response to said error signal to maintain said error signal at substantially zero.

11. A current regulating device for regulating current flow through a load over a wide range of current values comprising:

at least one input terminal;

at least one output terminal;

current control means connected between said input and output terminals to control the current therebetween to provide a controlled load current;

a plurality of impedance means;

means for connecting one of said plurality of impedance means in series between said current control means and said one output terminal;

a variable potential source;

means including at least one impedance means for connecting said variable potential source and said one impedance means in series between said current control means and said one output terminal, the voltage drop across said one impedance means due to a portion of said load current opposing the potential of said variable potential means thereby to produce an error signal; and

means connecting said error signal to said current controlling means, said current controlling means responsive to said error signal for controlling current flowing through said current control means to maintain said error signal at substantially zero.

12. A current regulating device for controlling current flow through a load over a wide range of current values comprising:

an input terminal;

an output terminal;

variable impedance means;

current sensing means for sensing the current to said output terminal;

means connecting said variable impedance means and said current sensing means in electrical series circuit between said input and output terminals;

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said current sensing means including first and second parallel connected branches, said first branch including a plurality of impedances and means for connecting one of said impedances in said branch; a potentiometer having a slider; 5 means applying a potential across said potentiometer; means connecting one set of said potentiometer to said variable impedance means; first and second impedance means; 10 means connecting said first and second impedance means in series between said slider and said output terminal whereby said first and second impedance means and the portion of said potentiometer between said slider and said one side of said potentiometer form said second branch, the potential across 15 said potentiometer opposing the voltage drop across said first impedance means developed by load current flowing therethrough, the impedance of said potentiometer being small with respect to said first impedance means whereby the potential developed across said portion of said potentiometer due to load current is negligible; 20

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amplifier means having its input connected across said portion of said potentiometer and said first impedance means and its output to said variable impedance means to control the impedance of said variable impedance means in response to the difference in potential at said slider and the voltage drop across said first impedance means.

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Assistant Examiners.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,370,222

February 20, 1968

Jan W. Haagen-Smit et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 8, line 56, after "signal" insert -- to maintain said error signal at substantially zero --; column 11, line 7, for "set" read -- side --.

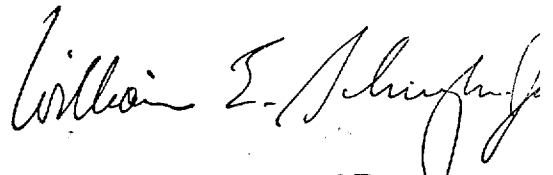
Signed and sealed this 20th day of May 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer



Commissioner of Patents