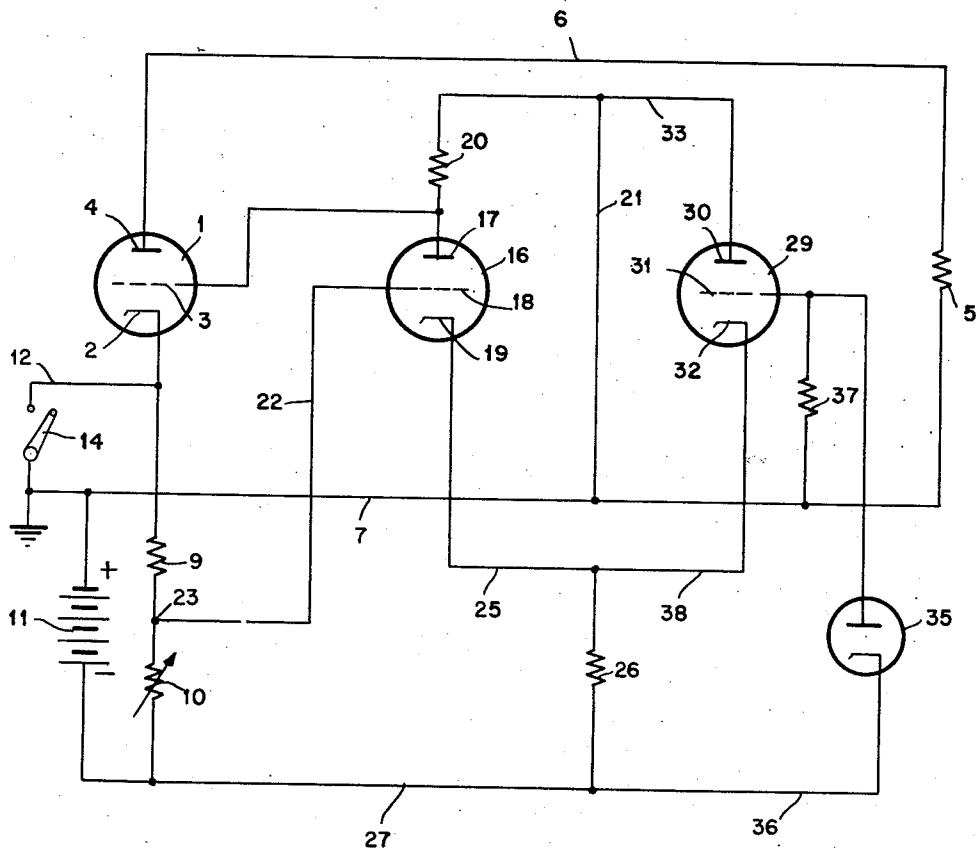


Sept. 24, 1957

A. W. LAMPE
CONSTANT CURRENT CIRCUIT
Filed Nov. 23, 1954

2,807,773



INVENTOR.
ALTMAN W. LAMPE
BY *Ralph C. Rustin*
ATTORNEY

1

2,807,773

CONSTANT CURRENT CIRCUIT

Altman W. Lampe, Poughkeepsie, N. Y., assignor to International Business Machines Corporation, New York, N. Y., a corporation of New York

Application November 23, 1954, Serial No. 470,697

2 Claims. (Cl. 323—4)

This invention relates to electronically regulated power sources and more particularly to an electronically regulated power source designed to produce a constant current output.

The basic requirement for constant current sources of the type in this invention is that the impedance of the load be only a small percentage of the total impedance of the circuit so that any variation in magnitude of the load impedance, even on the order of several times the load impedance value, will be very small in relation to the total impedance of the circuit.

The constant current circuit in this invention meets this basic requirement since the circuit provides an internal impedance so great that changes as much as 100 times the original load impedance magnitude are less than one part in 10,000 of the total circuit impedance. This is accomplished by providing a negative feedback amplifier coupled to the output stage to compensate for external impedance changes, and a further regulating stage connected to the negative feedback amplifier to compensate for internal circuit parameter changes and thereby keep the output of the negative feedback amplifier stage constant.

The principal object of this invention is to provide a simplified electronically regulated constant current circuit of improved reliability that will maintain a constant current output over a wide range of load impedance values.

Another object of this invention is to provide a simplified constant current circuit that is adjustable over a sufficient range to compensate for standard manufacturing tolerance variations in the replacement of components.

Still another object of this invention is to provide a simplified constant current circuit having internal compensating means whereby changes in value and operating point of the components in the circuit are not permitted to vary the circuit output.

Other objects of the invention will be pointed out in the following description and claims and illustrated in the accompanying drawings, which disclose by way of example, the principle of the invention and the best mode which has been contemplated of applying that principle.

In the drawings:

The figure is the basic circuit diagram of a constant current circuit illustrating the invention.

Referring now to the figure, a constant current circuit is illustrated having an output tube 1 comprising a cathode 2, a grid 3 and a plate 4. A load, shown as resistor 5, is connected at one end through a conductor 6 to the plate 4 and is connected at its other end through a conductor 7 to ground. The cathode 2 is connected to a fixed cathode resistor 9, the other terminal of resistor 9 being connected through an adjustable cathode resistor 10 to the negative terminal of a power and bias battery 11 having its positive terminal grounded. The cathode 2 is also connected through a conductor 12 and a manually operated control switch 14 to ground.

A negative feedback tube 16 comprising a plate 17, a

2

grid 18 and a cathode 19 is arranged with its plate 17 connected to grid 3 of tube 1 and also connected through a resistor 20, a conductor 21 and the conductor 7 to ground. The grid 18 is connected by a conductor 22 to a point 23 between resistors 9 and 10. Cathode 19 is connected through a conductor 25, a cathode resistor 26 and a conductor 27 to the negative terminal of battery 11.

An internal circuit regulating tube 29 is provided with a plate 30, a grid 31 and a cathode 32. The plate 30 is connected through a conductor 33 and the conductors 21 and 7 to ground. The grid 31 is connected to the plate of a voltage reference tube 35, the cathode of tube 35 being connected by a conductor 36 and the conductor 27 to the negative terminal of the bias battery 11. The grid 31 is also connected through a resistor 37 and the conductor 7 to ground. The cathode 32 is connected by a conductor 38 to the junction point between the conductor 25 and the resistor 26. The tubes 1, 16 and 29 are shown as triodes for simplicity only and may be replaced by other types with minor circuit changes which may readily be performed by one skilled in the art.

The constant current circuit is placed in operation by opening control switch 14 and adjusting resistor 10 to establish the desired current through the load 5. The opening of control switch 14 permits cathode 2 to drop below ground potential. An output current then flows from the positive side of battery 11 through load 5, output tube 1, coarse adjustment resistor 9 and fine adjustment resistor 10 to the negative terminal of battery 11. When this current is flowing, point 23 is at a value of potential below ground and this potential is applied to the grid 18 of the negative feedback amplifier tube 16. This provides a bias on the tube 16 and establishes a rate of conduction in tube 16 with the current flowing from ground through conductors 7 and 21, the resistor 20, tube 16 and cathode resistor 26 to the negative terminal of battery 11. The current in this stage places plate 17 at a value of potential below ground and, since plate 17 is connected to grid 3, a bias is provided on tube 1 to establish the rate of conduction by that tube. Thus, the adjusting of resistor 10 changes the potential at point 23 and varies the bias and rate of conduction in tube 16 which in turn varies the bias and rate of conduction in tube 1 and permits a selected output current to be established. Once the constant current circuit is placed in operation and adjusted to the desired output current value it will maintain that output current value independent of load magnitude or internal circuit parameter variations.

To be able to maintain a constant current output, the circuit must be capable of self adjusting its operation to compensate for changes that could affect the output current. These changes are of two types, which are, changes in the output circuit that directly affect the load current and changes in the circuit of the negative feedback amplifier which would indirectly affect the output current.

Taking first the possible changes that could affect the output current directly, these include a change in load impedance, a change in operating point of tube 1, a change in value of resistor 9, a change in value of resistor 10 and a change in magnitude of power supply voltage 11. Each of these has the effect of a change in impedance of the output stage of the circuit, the output stage of the circuit being the circuit from ground load 5, tube 1, resistor 9, resistor 10 and battery 11. Any change in impedance of this output stage would permit a change in current flow which would change the value of potential at point 23. For purposes of illustration an example in the form of a decrease in load resistor 5 is here described. The decrease would bring plate 4 more nearly to ground and, since grid 3 is at a fixed potential below ground, the effect of this is to increase the potential difference between plate 4 and grid 3 which is an increase in bias and

increases the conduction of tube 1. The increased conduction increases the current through resistor 10 and raises the potential of point 23 nearer to ground. Since grid 18 of negative feedback tube 16 is connected to point 23, grid 18 is then brought nearer to ground. The effect of this is to lower the potential difference between plate 17 and grid 18 and decrease the conduction of tube 16. Less current through tube 16 lowers the potential drop across resistor 20 and brings plate 17 nearer to ground. Since grid 3 is connected to plate 17, the bias on tube 1 is decreased and the conduction of tube 1 is reduced. This decrease in conduction returns point 23 toward the original point of potential and the circuit stabilizes at an operating point that will supply the original current output before the change occurred. Any change in any impedance in the output stage of the circuit will produce the same sequence of events as those described above with the direction of potential shifts being reversed for increases in impedance.

One circuit change that indirectly affects the output current is a variation in heater voltage of tube 16. To compensate for this item, an internal circuit regulating feature is added to the constant current circuit. This regulating feature includes tube 29 so connected as to prevent the output of tube 16 from being varied by any other factor than a change in bias. This is accomplished as follows: Tube 29 has its grid 31 held at a reference voltage by tube 35 and resistor 37. The current flows from ground through conductors 7, 21, 33, tube 29, and resistor 26 to the negative terminal of battery 11. The regulated potential difference between grid 31 and plate 30 provides constant bias and thereby keeps cathode 32, cathode 19 and the potential drop across resistor 26 constant. Any change in the heater voltage of tube 16 will appear as an increase in current through tube 16 and hence through resistor 26. The current through resistor 26 is made up of two parts, one going through tube 16 and the other going through tube 29. A change in potential drop across resistor 26 will bring cathode 32 into a new potential relationship with grid 31 and will vary the amount of conduction in tube 29 which in turn will vary the part of the current through resistor 26 that goes through tube 29. The change in current through resistor 26 will be in the direction to re-establish the original potential drop across resistor 26 and thereby keep the operating point of tube 16 constant.

The effect of the negative feedback amplifier coupled to the output stage of the constant current circuit is to produce a characteristic circuit impedance so great that major changes in load impedance are minute with respect to this characteristic impedance. To illustrate this point the constant current circuit of the invention will be described below in an embodiment designed to deliver 1 milliampere to the load. While it should be understood that the specifications for the circuit components may vary widely, and substitutions may readily be made by one skilled in the art to produce a constant circuit designed to deliver any magnitude of current to any size load, the following values are included by way of example only, it being understood that the invention is not to be limited to the values indicated:

Tube 1	½ 6J6.
Tube 16	½ 12AX7.
Tube 29	½ 12AX7.
Tube 35	5651 voltage reference.
Battery 11	300 v.
Resistor 9	60,000 ohms.
Resistor 10	90,000 ohms—variable.
Resistor 20	390,000 ohms.
Resistor 26	82,000 ohms.
Resistor 37	68,000 ohms.
Load 5	1,000 to 100,000 ohms.
Control 14	SPST switch.

This embodiment is designed to deliver 1 milliampere of constant current to a load that may vary from 1 to 100 times the original magnitude.

The total characteristic impedance of this constant current circuit may be expressed as the sum of two quantities. The first of these is the resistance of the output circuit which is made up of the cathode resistance and plate resistance of the output stage. The second quantity represents the impedance presented by the negative feedback amplifier and is made up of the product of the negative feedback signal and the total amplification from both the negative feedback and output tubes. This may be expressed by the product of a "quantity" and the cathode resistance of the output stage, this "quantity" being the product of the amplification factor of the output tube and the amplification of the negative feedback stage +1. This impedance may be described mathematically by the expression.

$$Z = R_K + R_P + (\mu(A+1))R_K$$

where:

R_K = cathode resistance of the output stage = 150 K in this embodiment.

R_P = plate resistance of the output stage = 40 K in this embodiment.

μ = amplification factor of the output tube = 28 in this embodiment.

A = gain of entire negative feedback stage =

$$\frac{-\mu'}{1 + \frac{R_P}{R_L}} = \frac{100}{1+1} = 50$$

in this embodiment.

Where:

μ' is the amplification factor of the negative feedback tube = 100 in this embodiment.

$$\frac{R_P}{R_L}$$

is the ratio of plate resistance to load resistance in the negative feedback stage and the ratio is approximately 1 in this embodiment.

Substituting:

$$Z = 150 \times 10^3 + 40 \times 10^3 + (28(50+1))150 \times 10^3$$

$$Z = 215 \times 10^6 \text{ ohms}$$

From the example shown above it may be seen that with an output impedance of 215 megohms a variation in load impedance from 1000 to 100,000 ohms, a change of 100 times, is but one part in the 10,000 of the total output impedance.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to a preferred embodiment it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention. For example by proper circuit design transistors may be used to replace vacuum tubes. It is the intention, therefore, to be limited only as indicated by the scope of the following claims.

What is claimed is:

1. A constant current circuit comprising a first tube including a plate, a grid and a cathode, an external load impedance, said first tube plate being connected to one terminal of said load impedance, the remaining terminal of said load impedance being connected to a point of common reference potential, a control switch having one terminal connected to said first tube cathode and having the remaining terminal connected to said point of reference potential, a first cathode resistor having one terminal connected to said first tube cathode, a variable second

5

cathode resistor having one terminal connected to the remaining terminal of said first cathode resistor, a source of D. C. power having the negative terminal connected to the remaining terminal of said variable second cathode resistor, the positive terminal of said D. C. power source being connected to said point of common reference potential, a second tube including a plate, a grid and a cathode having said second tube plate connected to said first tube grid, a plate resistor having one terminal connected to said second tube plate, the remaining terminal of said plate resistor being connected to said point of common reference potential, said second tube grid being connected to a point between said first and said second cathode resistors, a common cathode resistor having one terminal connected to said second tube cathode, the remaining terminal of said common cathode resistor being connected to said negative terminal of said D. C. power source, a third tube including a plate, a grid and a cathode, said third tube plate being connected to said point of common reference potential, a voltage reference tube including a plate and a cathode, said third tube grid being connected to said plate of said voltage reference tube, said cathode of said voltage reference tube being connected to said negative terminal of said D. C. power source, a grid resistor having one terminal connected to said third tube grid, the remaining terminal of said grid resistor being connected to said point of reference potential, and said third tube cathode being connected to said second tube cathode.

2. A constant current circuit comprising a D. C. power source having one terminal connected to a point of common reference potential, a first signal developing imped-

6

ance having one terminal connected to the remaining terminal of said D. C. power source, a second signal developing impedance having one terminal connected to the remaining terminal of said first signal developing impedance, an output amplifier including an input terminal, an output terminal and a control terminal having said input terminal connected to the remaining terminal of said second signal developing impedance, an external load having one terminal connected to said output terminal of said output amplifier, the remaining terminal of said external load being connected to said point of common reference potential, a negative feedback amplifier including an input terminal, an output terminal and a control terminal, circuit means comprising a regulated amplifier including an input terminal, an output terminal, said input terminal being connected to the input terminal of said negative feedback amplifier, said output terminal being connected to reference potential, said circuit means being operative to provide constant amplification in said negative feedback amplifier, circuit means to cause signals developed across said first and second signal developing impedances as a result of changes in output current to be applied to the input terminal of said negative feedback amplifier and further circuit means to apply signals in an amplified state from the output terminal of said negative feedback amplifier to the input terminal of said output amplifier to oppose changes of current therein.

References Cited in the file of this patent

UNITED STATES PATENTS

2,394,891 Bowie Feb. 12, 1946