

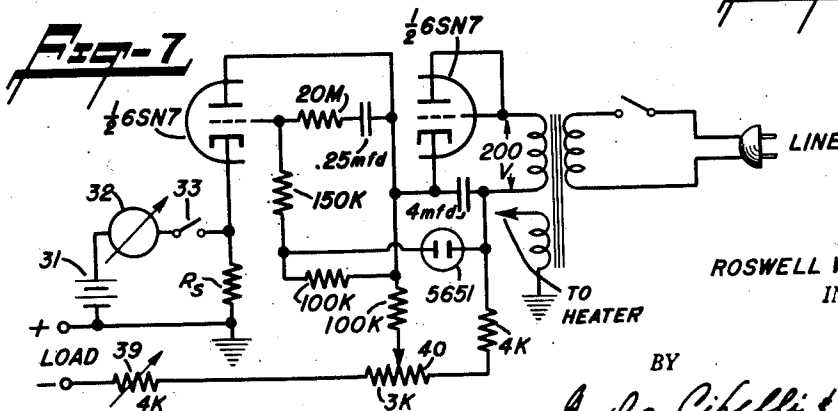
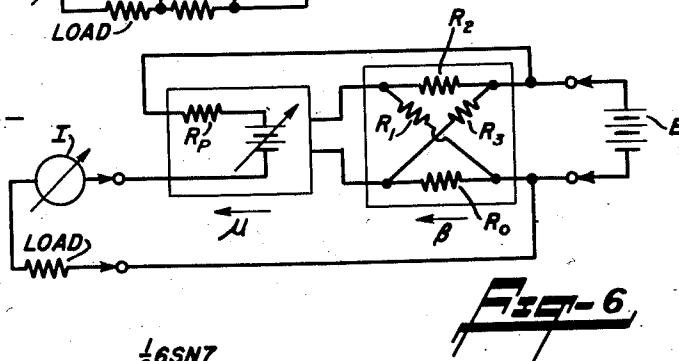
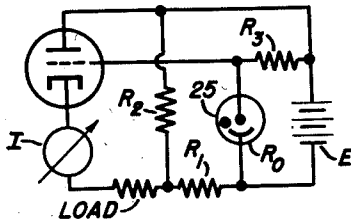
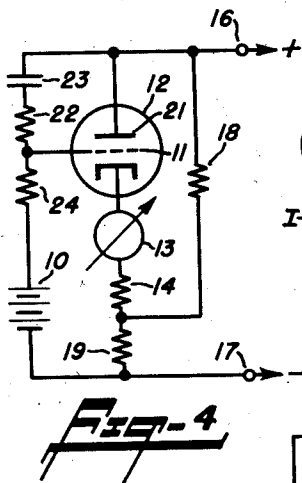
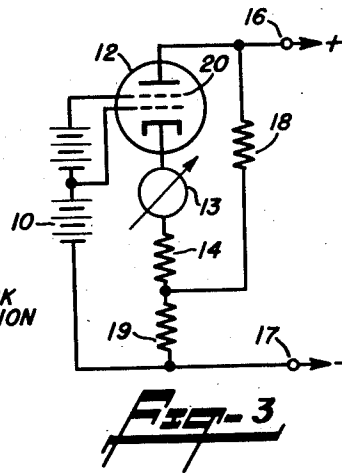
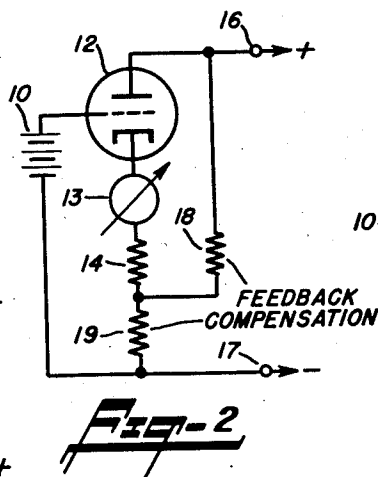
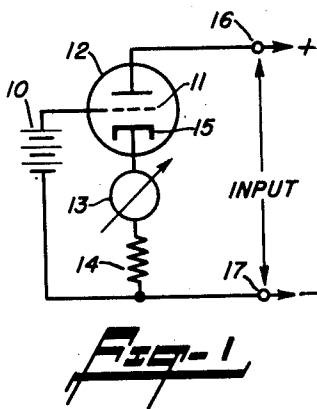
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CURRENT REGULATING SYSTEM

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CURRENT REGULATING SYSTEM

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1 Claim. (Cl. 323—4)

This invention relates to regulated current sources and more particularly to a D.-C. current regulator circuit including an electron tube and means compensating for the tube voltage ratio and cathode thermal influence thereon.

Numerous devices, particularly in the field of instrumentation, require a steady, or standardized, source of direct current. Regulated D.-C. supplies are available for this purpose but present devices of this class generally include regulation against load current burden changes as well as against line voltage changes. The present invention is directed to the provision of a novel and simplified circuit arrangement providing a regulated D.-C. current supply for application in those devices which involve substantially constant burden resistances. My novel circuits are derived by applying compensation to a basic cathode follower circuit and may be termed compensated cathode follower circuits. They include a degenerative bridge feedback network providing compensation for the voltage ratio (μ) of a tube and compensation of the cathode thermal influence upon such tube voltage ratio.

An object of this invention is the provision of a simplified D.-C. current regulator circuit.

An object of this invention is the provision of a regulated D.-C. current supply including an electron tube and a bridge type degenerative feedback circuit compensating for the tube voltage ratio and cathode thermal influence thereon.

An object of this invention is the provision of a regulated D.-C. current source of the type comprising an electron tube and a cathode follower circuit and including an R-C feedback circuit coupling the plate to the grid through a grid series resistor, said R-C circuit having a time-constant matched to the thermal time-constant of the cathode.

An object of this invention is the provision of a regulated D.-C. current source comprising an electron tube, voltage sources energizing the tube electrodes, circuit elements connected to the tube electrodes to form a cathode follower circuit, a degenerative feedback circuit connected between the tube plate and cathode and having a voltage attenuation ratio equal to the reciprocal of the tube voltage ratio, and an R-C feedback path coupling the tube plate to the grid through a grid series resistor, said R-C path having a time-constant matched to the thermal time-constant of the tube cathode.

These and other objects and advantages will become apparent from the following description when taken with the accompanying drawings. It will be understood the drawings are for purposes of illustration and are not to be construed as defining the scope or limits of the invention, reference being had for the latter purpose to the appended claim.

In the drawings wherein like reference characters denote like parts in the several views:

Figure 1 illustrates an elementary circuit of the cathode follower type connected to a steady reference potential;

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Figure 2 is similar to Figure 1 to which has been added a plate-cathode L network proportioned to supply the operating differential arising by reason of the change in the cathode potential as the plate voltage changes;

5 Figure 3 is similar to Figure 2 and including a conventional pentode connection to correct output current variations arising by reason of voltage inputs that are high or low with respect to the input level where regulation is perfect;

10 Figure 4 is similar to Figure 2 but including an R-C feedback path coupling the plate to the grid through a grid series resistor to compensate for the thermal drift of the tube cathode;

15 Figure 5 is a circuit diagram illustrating my compensated cathode follower circuit including a gas voltage regulator tube constituting the reference potential source;

Figure 6 is an equivalent four-terminal network; and Figure 7 is a circuit diagram of a regulated D.-C. current supply made in accordance with this invention.

20 Electronic regulators generally may be expressed as four terminal networks having a finite transfer immittance for direct current but zero transfer immittance for alternating current, or differential, components of input. When the zero transfer function is valid down to zero frequency, the output of the network will not be influenced by changes in input resulting, therefore, in a steady D.-C. output level regardless of input variations, within functional limits of the network. It will be appreciated that such a network must include at least one element that has a differential resistance unequal to its volt-ampere ratio. In common use for this purpose are such devices as lamp filaments, batteries, rectifier elements, thermistors and saturated thermionic cathodes. However, the most convenient such device is the cold-cathode gas tube which, in effect, presents a relatively constant potential in series with a nominal amount of differential resistance.

Reference is now made to Figure 1 which is a circuit diagram of an elementary current regulator, of the cathode follower class, connected to a steady reference potential such as the battery 10. The grid 11, of the tube 12, is connected to the battery and the output load device, here shown as the resistor 14, is connected in series with the indicating instrument 13 between the other side of the battery and the tube cathode 15. The input circuit to the regulator comprises the terminals 16, 17, adapted for connection to a source of plate voltage in accordance with the indicated polarity. As the plate voltage changes to alter the cathode current, the resulting change in cathode potential with respect to the grid corrects the plate resistance to minimize the current change, except for a small operating differential. Perfect regulation requires a vanishingly small operating differential which would obtain only if the tube transconductance be infinite.

55 Figure 2 illustrates a modification of the Figure 1 circuit. Specifically, a plate-cathode "L" network, comprising the resistors 18, 19, has been added to supply the operating differential above mentioned. As the plate voltage changes the added network transmits the change, properly attenuated, to the cathode circuit to exactly supply the grid-cathode potential shift required to correct the change in terms of cathode current. Correction obtains when the voltage-attenuation ratio of the added network equals the reciprocal of the tube voltage ratio (μ). The feedback direction is degenerative and cannot result in instability. Compensation is susceptible to variations in the tube voltage ratio with plate voltage level, the tube voltage ratio generally increasing with increasing plate voltage. Thus, characteristically, the system will be over-corrected at input levels higher than design center and under-corrected for input levels lower than design center. When properly adjusted at the design center input level, the output current will have a second order

variation causing a slight decrease with actual inputs that are high or low relative to the input level where regulation is perfect. This second order variation is very small and varies approximately as the square of the input level deviation from design center. It can easily be made smaller than 2.5×10^{-4} times the input level change-ratio squared. Theoretically, this error can be reduced by recourse to the pentode connection shown in Figure 3. A study of Figure 3 will show that it is similar to Figure 2 with the addition of the pentode screen grid 20 to the electron tube. However, the Figure 3 combination is rather superfluous in view of thermal drift of the cathode as an intervening limitation. Further, the screen current demand of the pentode connection involves practical complications.

All circuit elements are subject to thermal drifting but that originating by reason of the temperature coefficient of the tube cathode contact potential is the most obviously large. If the circuit is adjusted for optimum regulation against rapid input level changes the following cathode temperature change with heater voltage will cause drift. Alternatively, if the circuit is adjusted to accommodate cathode temperature drift as a steady state correction, it will be subject to over-correction for rapid input level changes. This effect could be minimized by separate regulation of the heater supply voltage but as a sacrifice of circuit simplicity. Also, the stated effect could be reduced to a second order by a second tube element in compensating relationship but with similar objection.

As measured in typical types of electron tubes, the cathode contact potential changes about 10 millivolts per percent of cathode heater voltage change near design center. The thermal time constant is about 5 seconds for small receiving tube cathodes. In a circuit using a 60 volt gas tube as a reference potential, this would produce a thermal drift of $\frac{1}{60}$ of the input change, or an output change of 0.25 percent for a typical input level change of 15 percent. This is limiting to a system otherwise capable of regulating the same input level change to better than 0.05 percent and, therefore, requires correction.

My simple arrangement for compensating the cathode thermal drift is shown in Figure 4 which basically is similar to Figure 2. The cathode thermal drift compensator comprises the resistor 22 and capacitor 23 forming an R-C feedback path coupling the plate 21 to the grid 11 through a grid series resistor 24. The R-C circuit has a time-constant matched to the thermal time-constant of the tube cathode. This feedback circuit degenerates the tube voltage ratio slightly, requiring some additional compensation for instantaneous input level changes, but it becomes ineffective in the steady state condition allowing the slight measure of over-compensation to include correction for cathode thermal drift. By proper adjustment of this feedback magnitude, and the time-constant and magnitude of the main compensation feedback, the circuit is made stable for both rapid and slow changes of input level.

Thus far, for simplicity of illustration, the reference potential sources have been shown as batteries. In practice, however, gas voltage-regulator tubes are employed for the purpose. The differential resistance of such gas tubes is slightly influential upon regulation but such effects can be included in the compensation adjustment.

Figure 5 illustrates a circuit diagram of my compensated cathode follower arrangement including a gas voltage-regulator tube 25 and with the compensating bridge elements here identified as R_1 , R_2 , R_3 and R_0 , the latter being the differential resistance of the regulator tube 25.

Figure 6 illustrates the equivalent, four-terminal network with the tube voltage ratio (μ) in the feedback loop with the voltage transfer function (β) of the bridge.

The transfer conductance (G) of the system may then be expressed as

$$G = \frac{dI}{dE} = \frac{1 - \mu\beta}{R_p} \quad (1)$$

where

E is the input voltage,

I is the output current, and

R_p is the plate resistance of the tube 12.

The point of perfect regulation is where $G=0$; when no differential current I will flow with differential voltage E . This obtains when the factor $(1 - \mu\beta) = 0$, or

$$\beta = \frac{1}{\mu} \quad (2)$$

and the system becomes independent of R_p .

The voltage transfer function (β) of the bridge is:

$$\beta = \frac{R_1 R_3 - R_0 R_2}{R_1 R_3 + R_2 R_3 + R_0 R_1 + R_0 R_2} \quad (3)$$

so that the bridge relationship should be:

$$\frac{R_1 R_3 + R_2 R_3 + R_0 R_1 + R_0 R_2}{R_1 R_3 - R_0 R_2} = \mu \quad (4)$$

It is pointed out that if the voltage reference tube 25 were ideal and $R_0=0$, Equation 4 would reduce to:

$$\frac{R_1 + R_2}{R_1} = \mu \quad (5)$$

It will now be apparent that the circuit of Figure 5, including the practical voltage reference tube 25, may be combined with the cathode thermal compensating elements 22, 23 and 24 of Figure 4 in a practical operating circuit as shown in Figure 7. In this circuit a dual-triode tube, Type 6SN7, is used; one triode section serves as a current control tube as in Figure 5, and the other triode section is diode-connected to serve as a supply-power rectifier in a conventional manner. The voltage reference tube is a Type 5651 which is a very stable gaseous-discharge voltage regulator. The output load circuit includes a resistor R_s of appropriate value, the voltage drop across which can be balanced against a standard cell 31 by means of a galvanometer 32 through a switch 33 to standardize the output current. The primary adjustment of output current is the variable resistor 39. A second variable potentiometer resistor 40 serves to balance the regulation of the system to the point where changes of output current in response to line voltage changes are a minimum. The circuit values indicated are designed for an output current of 5 milliamperes.

Having now described my invention in detail in accordance with the patent statutes what I desire to protect by Letters Patent of the United States is set forth in the following claim.

I claim:

An arrangement for maintaining a substantially constant flow of current in a circuit energized by a D.-C. voltage source that is subject to variations, said arrangement comprising an electron tube having an anode connected to the positive side of said D.-C. voltage source, a cathode and a control electrode; a reference source of constant D.-C. voltage having one side connected to the said control electrode and the other side connected directly to the negative side of the said D.-C. voltage source; a first resistive connection between the cathode and the negative side of said D.-C. voltage source and a second resistive connection between the said anode and cathode, the values of the said resistive connections being such as to maintain a substantially constant current flow in the cathode circuit throughout the range of variations of said D.-C. voltage source; and an R-C circuit coupling the said anode to the control electrode, said R-C circuit

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having a time-constant matched to the thermal time constant of said cathode.

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