

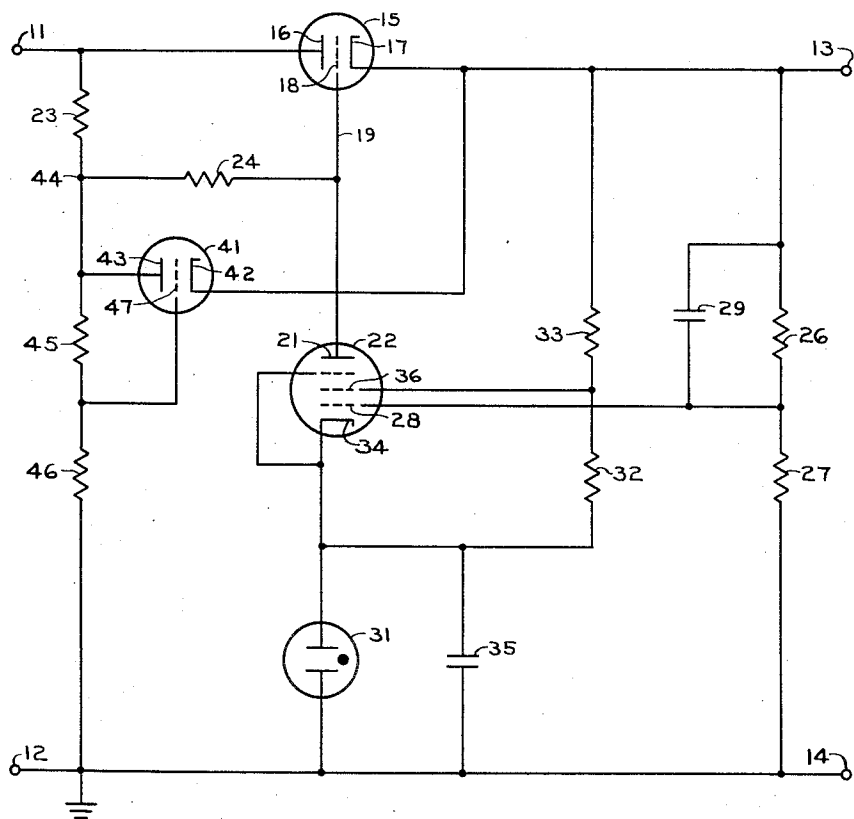
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A. H. FREDRICK

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VOLTAGE REGULATOR

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INVENTOR.
ARDEN H. FREDRICK

BY

A. S. Mackay.

ATTORNEY.

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VOLTAGE REGULATOR

Arden H. Fredrick, Mount Kisco, N. Y., assignor to General Precision Laboratory Incorporated, a corporation of New York

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This invention relates to electronic voltage regulators, particularly to that class of regulators in which a series tube has its conductivity varied in response to changes in the output voltage.

Regulators of the above class are widely employed to deliver a substantially constant unidirectional output voltage from a unidirectional supply voltage in spite of fluctuations in the supply voltage or in the current drawn by the load. An electron tube is connected in series with the supply voltage and has its grid connected to the anode of an amplifier tube. The grid of the amplifier is connected to a voltage divider across the output, the anode is connected through a load resistor to the input, while the cathode is connected to a reference voltage. Thus variations in the output voltage are amplified and applied to the grid of the series tube so as to counteract the changes in output voltage.

Regulators such as above described are widely used and are quite satisfactory but are subject to the disadvantage that the connection between the input and the grid of the series tube causes variations in the input voltage to be impressed upon the grid where they are amplified and appear in the output. Of course, the input variations are but a portion of the total voltage on the grid of the series tube but nevertheless limit the efficacy of the regulation.

Various schemes have been proposed to modify the regulator so as to eliminate this effect. In one arrangement, a capacitor is connected between an intermediate point of the amplifier tube load resistor and ground. The filtering action of this resistor capacitor combination reduces the amplitude of the high frequency components of the input voltage fluctuations which reach the grid of the series tube but has no effect on the low frequency components. In another arrangement, sometimes called a "mu bridge," the amplifier tube is a pentode having its screen connected to a voltage divider across the input so that the input variations are amplified sufficiently to cancel the variations transmitted to the grid of the series tube through the amplifier tube load resistor. This arrangement operates very well when adjusted properly but requires frequent, careful adjustment and must be completely re-balanced when tubes are changed. A third arrangement has the grid of the series tube and the anode of the amplifier tube connected together and, through a resistor, to the output side of the series tube. Thus variations in the input are not transmitted to the grid of the series tube. However, this arrangement has the disadvantage that the series tube must operate with a high negative grid bias if there is to be sufficient drop across the anode load resistor of the amplifier tube to allow this tube to function properly. Thus the series tube is not utilized efficiently since it cannot pass its rated current and always has a large voltage drop across it.

An object of this invention is to provide an electronic

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regulator for maintaining a unidirectional output voltage substantially constant despite variations in the unidirectional input voltage and in the load current.

Another object of the invention is to provide a voltage regulator in which the low frequency components of input voltage variations are prevented from affecting the output voltage.

Another object of the invention is to provide a voltage regulator in which components may be replaced without requiring readjustment of the apparatus.

Another object of the invention is to provide a voltage regulator in which the components are utilized efficiently.

Briefly stated, the invention comprises a standard voltage regulator circuit to which there is added an additional electronic tube. This additional tube has its anode connected to an intermediate point on the anode load resistor of the amplifier tube so that the additional tube and the amplifier tube have, in part, a common anode load resistor. The conductivity of the additional tube is varied in response to input voltage variations thereby varying the voltage drop across the common portion of the load resistor and tending to maintain the potential of the grid of the series tube constant despite input voltage fluctuations.

For a clearer understanding of the invention, reference may be made to the following detailed description and the accompanying drawing, the single figure of which is a schematic diagram of a specific embodiment of the invention.

Referring now to the drawing, the unidirectional voltage to be regulated is applied to terminals 11 and 12 and the regulated output is taken from terminals 13 and 14. An electronic tube 15 is connected in series with the positive lead, having its anode 16 connected to input terminal 11 and its cathode 17 connected to output terminal 13. The control grid 18 is connected by a conductor 19 to the anode 21 of a pentode amplifier tube 22. Serially connected resistors 23 and 24 are connected between the input terminal 11 and the conductor 19 to furnish anode voltage for the pentode 22.

Serially connected resistors 26 and 27 are connected between output terminals 13 and 14 to constitute a voltage divider. The junction of these resistors, the potential of which is proportional to the output voltage, is connected to the control grid 28 of the pentode 22. A capacitor 29 is connected across the resistor 26.

A constant voltage glow discharge tube 31 has its negative electrode connected to the ground bus connecting terminals 12 and 14 and has its positive electrode connected through series connected resistors 32 and 33 to the output terminal 13. The positive electrode of the tube 31, the potential of which remains substantially constant, is connected to the cathode 34 of the pentode 28. A capacitor 35 is connected across the tube 31. The screen grid 36 of the pentode is connected to the junction of resistors 32 and 33.

The apparatus so far described constitutes a conventional voltage regulator. The invention comprises the addition of an electronic tube 41 the cathode 42 of which is connected to the output terminal 13. The anode 43 is connected to the junction 44 between resistors 23 and 24, which junction is also connected through resistors 45 and 46 to the common negative terminal. The control grid 47 of the tube 41 is connected to the junction of resistors 45 and 46.

In the absence of tube 41 and resistors 45 and 46, the apparatus is a conventional voltage regulator. The series tube 15 may be thought of as an element the resistance of which is adjusted by varying the potential of the grid 18. Variations in the output voltage appear on the grid

28 of the amplifier tube 22 and cause corresponding variations in the potential of anode 21, and grid 18, of the proper polarity to adjust the resistance, or conductivity, of the series tube 15 in such a sense as to compensate for the change in output voltage.

Continuing the analysis, assuming the tube 41 and resistors 45 and 46 to be absent, consider the effect of input voltage variations on the output voltage. If the potential of the input terminal 11 becomes more positive, this increase is transmitted through the resistors 23 and 24 to the grid 18 which increases the conductivity of tube 15 thereby decreasing the voltage drop across the tube and causing the output voltage on terminal 13 to rise. Of course this effect is overcome by the action of the amplifier tube 22 which decreases the potential of the grid 18 in response to an increase in the output voltage. In other words, a change in input voltage causes two components of voltage variation to appear on grid 18, one component due to the input voltage variation itself and the other due to the action of the amplifier tube 22. It can be shown by straightforward circuit analysis that the ratio of output voltage variations to input voltage variations can be expressed as

$$\frac{e_o}{e_i} = \frac{1 + \mu}{\frac{r_p}{R_L} + 1 + \mu(A + 1)} \quad (1)$$

where

e_o =change in output voltage;

e_i =change in input voltage;

μ =amplification factor of tube 15;

r_p =plate resistance of tube 15;

R_L =load resistance;

A =voltage amplification of tube 22; and the plate resistance of tube 22 is assumed to be infinite.

Equation 1 can be approximated by the expression

$$\frac{e_o}{e_i} = \frac{1}{A} \quad (2)$$

If the direct effect of input voltage variations on the grid 18 were absent, the ratio of output voltage variations to input voltage variations would become

$$\frac{e_o}{e_i} = \frac{1}{\frac{r_p}{R_L} + 1 + \mu(A + 1)} \quad (3)$$

Equation 3 can be approximated by the expression

$$\frac{e_o}{e_i} = \frac{1}{\mu A} \quad (4)$$

Equation 4 shows that the elimination of input variations from the grid would improve the regulation by a factor of μ , and the present invention obtains improved regulation by reducing these variations. The operation may be explained qualitatively by considering what happens when the voltage at terminal 11 rises, for example. Resistor 23 is small compared to resistors 24, 45 and 46 so that a large part of the current flowing through resistor 23 is that drawn by the tube 41. The cathode 42 is connected to the regulated output and therefore may be considered to remain nearly constant. If the voltage at terminal 11 rises, a portion of the rise will be impressed on the grid 47 causing tube 41 to draw more current through resistor 23. This, in turn, causes the potential of anode 43 and junction 44 to fall, thus opposing the original rise in potential and preventing the rise from being passed to the grid 18.

It can be shown that the ratio of output voltage variation to input voltage variation is

$$\frac{e_o}{e_i} = \frac{\frac{R_1 + r_1}{r_2} + \frac{1 + \mu_1}{1 + \mu_2 B}}{\frac{R_1}{r_2} \left[\frac{r_1}{R_L} + 1 + \mu_1(A + 1) \right] + \frac{1}{1 + \mu_2 B} \left[\frac{r_1}{R_L} + 1 + 1 + \mu_1(A + 1) + \frac{r_1}{r_2} (1 + \mu_2) \left(1 - \mu_1 \frac{R_1}{r_1} \right) \right]} \quad (5)$$

where

R_1 =resistor 23 (R_{23})

r_1 =Plate resistance of tube 15

r_2 =plate resistance of tube 41

5 R_L =load resistance

μ_1 =amplification factor of tube 15

μ_2 =amplification factor of tube 41

$$B = \frac{R_{45}}{R_{45} + R_{46}}$$

10 A =voltage amplification of the pentode stage

By considering the relative magnitudes of the various parameters in a reasonable, practical circuit, Equation 5 can be simplified to the approximation

$$\frac{e_o}{e_i} = \frac{2}{\mu_1 A} \quad (6)$$

A comparison of Equation 2, 4 and 6 shows that a circuit according to the invention, while not achieving an improvement factor of μ , does improve the performance vastly over that of the standard circuit. Tests conducted on a model have demonstrated the improvement indicated by analysis.

Although a specific embodiment has been described in detail, many modifications may be made within the scope of the invention. It is therefore desired that the invention be limited only by the true scope of the appended claims.

What is claimed is:

30 1. In a unidirectional voltage regulator in which a first electronic tube having its anode and cathode connected to an input terminal and an output terminal respectively has its conductivity controlled by the anode potential of a second electronic tube which receives its anode potential through a load resistance connected to said input terminal and the conductivity of which is responsive to output voltage variations, the improvement which comprises a third electronic tube having its anode connected to an intermediate point on said load resistance and the conductivity of which is responsive to input voltage variations.

40 2. An electronic unidirectional voltage regulator comprising first and second input terminals, first and second output terminals, a first electronic tube having its anode connected to said first input terminal and its cathode connected to said first output terminal, a second electronic tube having its conductivity controlled in response to the output voltage and having its anode connected to the control electrode of said first tube and also connected, through a resistance, to said first input terminal, and a third electronic tube having its anode connected to an intermediate point of said resistance and having its conductivity controlled in response to the input voltage.

50 3. An electronic unidirectional voltage regulator comprising first and second input terminals, first and second output terminals, a first electronic tube having its anode connected to said first input terminal and its cathode connected to said first output terminal, a second electronic tube having its conductivity controlled in response to the output voltage and having its anode connected to the control electrode of said first tube and also connected through a resistance, to said first input terminal, and a third electronic tube having its anode connected to an intermediate point of said resistance, its control electrode connected to an intermediate point on a voltage divider across the input, and its cathode connected to a point of stable potential.

70 4. An electronic unidirectional voltage regulator comprising first and second input terminals, first and second

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output terminals, a first electronic tube having its anode connected to said first input terminal and its cathode connected to said first output terminal, a second electronic tube having its conductivity controlled in response to the output voltage and having its anode connected to the control electrode of said first tube and also connected, through a resistance, to said first input terminal, and a third electronic tube having its anode connected to an intermediate point of said resistance, its control electrode

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connected to an intermediate point on a voltage divider connected between its anode and said second input terminal, and its cathode connected to said first output terminal.

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