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ELECTRONIC VOLTAGE REGULATOR

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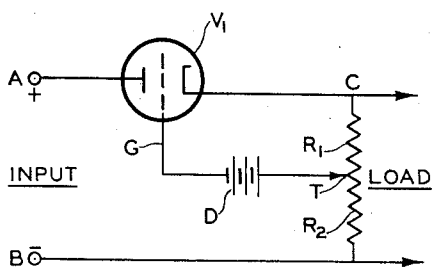


FIG. 1.

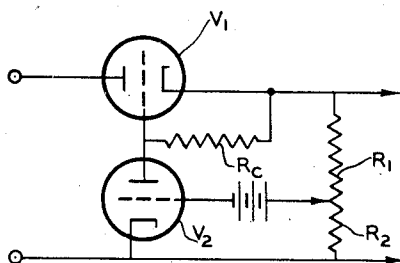


FIG. 2.

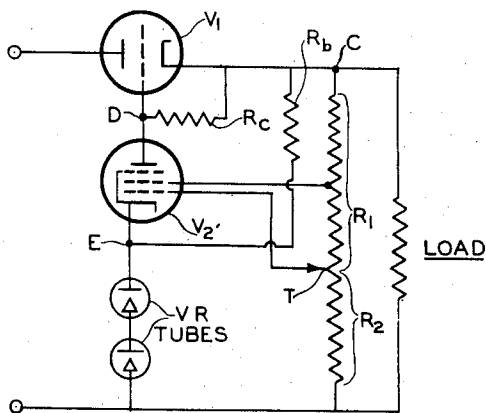


FIG. 3.

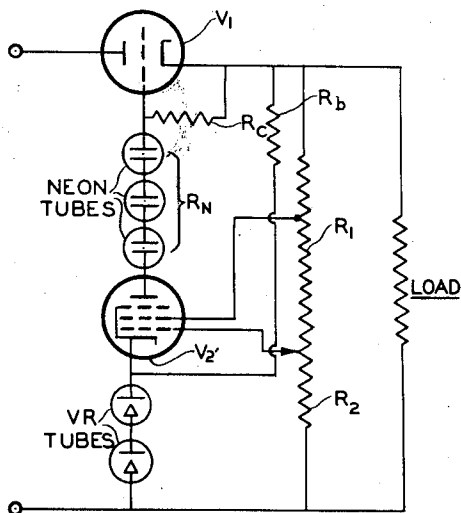


FIG. 4.

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ELECTRONIC VOLTAGE REGULATOR

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2 Claims. (Cl. 171-119)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates to electronic voltage regulators.

It is a principal object of the invention to provide an electronic regulator which is reduced in size and thus feasible for use with compact portable equipment.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, wherein like reference characters indicate equivalent elements, and wherein:

Figs. 1-3 are schematic circuits illustrating prior circuits; and

Fig. 4 is a schematic circuit of my invention.

Fig. 1 illustrates one basic type of regulator, the degenerative type. It consists of an amplifier tube V1, a bias battery D, and the load R1 and R2. The voltage of battery D and the tap T between resistors R1 and R2 are chosen so that the control grid of the tube will never be at a positive potential with respect to the cathode.

If the input voltage in such a circuit increases by a small amount, the voltage across the load will tend to increase. Any such increase, however, will make the control grid more negative with respect to the cathode. Amplification of this grid voltage increment increases the plate cathode potential so that the load voltage change is offset. Stated mathematically:

$$\Delta E_{in} = \Delta E_{p1} + \Delta E_o \quad (\text{from the existing potential distributions})$$

$$\Delta E_{p1} = -\mu_1 \Delta E_{g1} \quad (\text{from the definition of } \mu)$$

$$\Delta E_{g1} = -\Delta E_o \frac{R_1}{R_1 + R_2} = -\Delta E_o \gamma \quad (\text{from the existing potential distributions})$$

Hence:

$$\Delta E_{p1} = \Delta E_o \gamma \mu_1$$

and

$$\Delta E_{in} = \mu_1 \gamma \Delta E_o + \Delta E_o$$

The stabilization factor S is given by:

$$(1) \quad S = \frac{\Delta E_{in}}{\Delta E_o} = \mu_1 \gamma + 1 \cong \mu_1 \gamma$$

Where

ΔE_{in} = incremental increase in input voltage (point A with respect to point B)

ΔE_o = incremental increase in output voltage (point C with respect to point B)

ΔE_{p1} = incremental increase in plate voltage (point A with respect to point C)

ΔE_{g1} = incremental increase in grid voltage (point G with respect to point C)

$$\gamma = \frac{R_1}{R_1 + R_2}$$

μ_1 = amplification factor of tube V1

From this result it may be seen that the tap T should be as close to point B as feasible to make γ large, and that the μ of the tube should be large. The former, however, requires a large compensating voltage to maintain the grid negative, and the latter requires higher input voltage and greater tube dissipation than required with a low μ tube for the same load. A compromise design is therefore usually necessary.

A very desirable feature of this circuit is that the output voltage may be varied continuously by moving the tap T. Furthermore it is possible to introduce a D. C. amplifier between tap T and the control grid, thus greatly increasing the stabilization factor. Such a circuit is shown in Fig. 2. Here the static plate current of tube V2, flowing through the coupling resistor R_c, furnishes grid bias for the degenerative amplifier V1.

Fig. 3 shows several improvements that can be made in this circuit. Instead of a triode, a pentode V2' is used to obtain more gain. The cathode of V2' can be raised in potential by means of one or more gaseous voltage regulators of the VR type, so that battery D (which will occupy more space and have more weight than its equivalent in VR tubes) can be dispensed with. R_b is a bleeder resistor for the VR tubes. And finally R₁ and R₂ can be made independent of the load, as shown. The screen voltage of the pentode is obtained from a tap on R₁ so that this voltage and consequently the mutual conductance, g_{m2} , between control grid and anode of the tube is as constant as possible.

Examining this circuit we see that if the mutual conductance of the tube at the chosen operating potentials is g_{m2} , the voltage amplification will be approximately $g_{m2} R_c$, provided the plate resistance of V2' is considerably greater than R_c, where g_{m2} is the mutual conductance of V2'. The remainder of the circuit can be analyzed as follows:

$$\left. \begin{aligned} \Delta E_{in} &= \Delta E_{p1} + \Delta E_o \\ \Delta E_{p1} &= \mu_1 \Delta E_{g1} \end{aligned} \right\} \text{as before}$$

$$\Delta E_{g1} = \Delta E_{g2} g_{m2} R_c \quad (\text{due to voltage gain } g_{m2} R_c \text{ of } T_2)$$

$$\Delta E_{g2} = \Delta E_o \frac{R_2}{R_1 + R_2} = \Delta E_o (1 - \gamma) \quad (\text{from existing potential distributions})$$

Hence:

$$\Delta E_{p1} = \Delta E_o \mu_1 g_{m2} R_c = \Delta E_o (1 - \gamma) \mu_1 g_{m2} R_c$$

$$\Delta E_{in} = \Delta E_o (1 - \gamma) (\mu_1 g_{m2} R_c) + \Delta E_o$$

The stabilization factor is now:

$$(2) \quad S = \frac{\Delta E_{in}}{\Delta E_o} = (1 - \gamma) (\mu_1 g_{m2} R_c) + 1 \cong (1 - \gamma) \mu_1 g_{m2} R_c$$

Where:

ΔE_{in} , ΔE_o , ΔE_{p1} , μ_1 , γ , and g_{m2} are defined as before
 ΔE_{p1} =incremental increase in grid voltage of tube

V1 (point D with respect to point C)

ΔE_2 =incremental increase in grid voltage of tube
 V2' (point T with respect to point E)

Equation 2 is not quite rigorous, since negative current feedback occurs in the cathode circuit of V2', the VR tubes having some internal impedance. The voltage of an amplifier with feedback is given by the well known equation:

$$G = \frac{A}{1 - A\beta}$$

where:

A=gain of amplifier without feedback

β =fraction of output voltage fed back to input

In this case,

$$\beta = -\frac{Z_k}{R_c} \text{ and } A = g_{m2}R_c$$

where Z_k =dynamic impedance of VR tubes in cathode circuit. Hence

$$G = \frac{g_{m2}R_c}{1 + g_{m2}Z_k} = \alpha A$$

Therefore the stabilization factor of (2) is too great by the factor

$$\alpha = \frac{1}{1 + g_{m2}Z_k}$$

and should be written

$$(3) \quad S = \frac{(1 - \gamma)\mu_1 g_{m2}R_c}{1 + g_{m2}Z_k}$$

For a 5000 volt supply, approximately thirty one, type VR 150 tubes are needed if V2' is to be a receiving type tube and γ is to be made small. Assuming $g_{m2} \approx 400 \mu$ mhos at the operating point and that the Z_k for each VR 150 is a resistance of 120 ohms, a value frequently obtained, the gain is reduced by the factor $\alpha \approx 0.4$, that is 60% of the available stabilization is lost. For a low voltage supply, using a single VR 105 operated so that $Z_k = 40$ ohms, resistive, and $g_{m2} = 400 \mu$ mhos, $\alpha \approx .984$, and the loss of stabilization due to current feedback is negligible.

A regulated high voltage supply having thirty one VR tubes is of course not small, and would be out of the question in portable or airborne equipment. The use of small neon bulbs in place of the larger VR tubes in the cathode circuit will not solve the problem as these have a much higher internal impedance than the VR tubes and, since their operating voltage is usually around 75 volts, a larger number of neon tubes would be required.

In accordance with the present invention, one to six VR tubes are used to provide a reference voltage with which the varying voltage is compared. As many VR tubes as space permits should be used to make γ small. V2' is a receiving type pentode. The plate of V2' is coupled to the grid of V1 by as many neon bulbs as are needed to make the plate voltage of V2' a safe value. These bulbs may be of the $\frac{1}{2}$ watt variety which are only $\frac{1}{4}$ " in diameter and 1" long, thus requiring very little space to obtain a large and fairly constant voltage drop. The internal impedance of these at 60 cycles is about 5000 ohms, and twenty of them used in series to obtain 1500 volts drop constitute a resistance R_n of about 100,000 ohms. R_n and R_c form a voltage divider, so that the amplification of the circuit is reduced by the factor

$$\frac{R_n}{R_n + R_c}$$

In the case cited above the gain is reduced $1/11 \approx 9\%$ for $R_c = 1$ megohm, a customary value.

The stabilization factor is now given by

$$(4) \quad S \approx (1 - \gamma)\mu_1 g_{m2}R_c \cdot \frac{1}{1 + g_{m2}Z_k} \cdot \frac{R_n}{R_n + R_c}$$

It may be seen then that, by using this circuit, greatly reduced size is achieved at the cost of somewhat reduced stabilization. The use of this scheme is best illustrated by a continuation of the above example. For a 2000 volt supply, ten VR 150 tubes would ordinarily be used. These occupy a volume of 62.5 cubic inches and have $Z_k = 1200$; $\gamma \approx .1$; $\mu_1 = 4$; $g_{m2} = 400 \mu$ mhos; $R_c = 1$ meg; and $R_n = 0$. This makes $S = 970$. If instead we use only three VR 150 tubes and nine $\frac{1}{2}$ watt neons with other things the same, the following results are achieved: $R_k = 360$; $R_n = 45,000$; $\gamma = .73$; $S = 266$, and the volume of gas tubes is 19.9 cubic inches.

While there has been described what is at present considered a preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. In combination with a source of direct current power and a load circuit, a voltage regulator comprising a grid-controlled electron tube having its space-current path connected in series with said source and load circuit, and a direct current amplifier having its input controlled by the voltage across said load circuit and its output coupled to the grid of said electron tube; said amplifier comprising a second electron tube having its grid controlled by at least a portion of the voltage across the load circuit, its cathode connected in series with a relatively low impedance gaseous discharge path to the low potential side of said load circuit, and its anode connected in series with a relatively high resistance gas discharge path and a resistor to the high potential side of said load circuit, the junction between said resistor and said discharge path being connected to the grid of said first electron tube.

2. In combination with a source of direct current power and a load circuit, a voltage regulator comprising a grid-controlled electron tube having its space-current path connected in series with said source and load circuit, a resistor connected across said load circuit, and a direct current amplifier having its input controlled by the voltage across said resistor and its output coupled to the grid of said electron tube; said amplifier comprising a second grid-controlled electron tube having its grid connected to a tap on said resistor, its cathode connected in series with one or more gaseous, low-impedance voltage-regulator tubes to the low potential side of said resistor, and its anode being connected in series with a plurality of relatively high resistance neon tubes and a resistor, in the order named, to the high potential side of said first resistor, the junction between the second resistor and said neon tubes being connected to the grid of said first electron tube.