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VOLTAGE-REGULATED POWER SUPPLIES

Stabilized operation and constant calibration of all types of electronic equipment require that fluctuations in the operating voltages and currents supplied to such equipment be held to a minimum. The frequency of a self-excited oscillator, for example, will shift quite a few hundred parts per million, depending upon frequency, when the plate voltage of the oscillator tube is changed slightly. Output power and impedance of an amplifier likewise follow changes in plate voltage.

Voltage-regulated power supplies have been developed to deliver a practically constant output voltage although the input voltage to the unit or the output current drawn from the unit fluctuate considerably. Current regulators also are available for those applications in which current values must be held constant although the load voltage fluctuates.

This article describes circuits and devices for voltage and current regulation. It has been our aim to include enough practical data in this discussion to enable the reader to construct automatically-regulated power supplies either for external use or to be built into other electronic equipment.

Gaseous-Tube Voltage Regulators

The simplest voltage regulating device lending itself to inclusion readily into any d. c. power supply is the gaseous regulator tube, also known as a glow tube. These tubes currently are manufactured in the following types: OA2, OA3/VR75, OC3/VR105, OD3/VR150, and 874. Also obtainable is the VR90-30 (also called OB3) which still is on the market but has been dropped from some manufacturer's lists. The OA3 supplies 75 volts of regulated d. c.; the VR90 and 874, 90 volts; OC3, 105 volts; and the OA2 and OD3, 150 volts. Used intelligently, these tubes (or combinations of them) afford a simple means of obtaining reasonably constant d. c. potentials from conventional rectifier-filter systems.

The gaseous regulator tube operates on the principle that a constant voltage drop appears across the tube regardless of the current flowing through it, once the ignition potential of the gas has been reached. The maximum current which may be passed through each of the regulator tubes except types 874 and OA2 is 40 milliamperes. Maximum current rating of the 874 is 50 ma., and for the OA2, 30 ma. At all times, the current from the filter output of the power supply is divided between the regulator tube and the output (load) circuit. As more current is drawn by the load, less current flows through the tube. A minimum current of 5 ma. must flow through the tube at all times (10 ma. for the 874), otherwise the gas discharge will be extinguished and regulation will be lost.

All gaseous regulator tubes will hold the d. c. output voltage constant within a few volts. The following control figures are given by the tube manufacturers: OA2, 2 volts; OA3, 5 volts; OC3, 2 volts; OD3, 4 volts; VR90, 8 volts; and 874, 7 volts. This means that the output with type OD3 will be 150 volts within 2 volts, the OA3 75 volts within 2 volts, etc., etc. When closer regulation than these values is required, some system of automatic voltage regulation other than gaseous tubes should be used.

Figures 1 and 2 show typical gaseous-tube voltage regulator circuits.

Figure 1 is the basic arrangement. R is a series resistor used to limit the current through the tube. The size of this resistor is very important to operation of the circuit. The ohmic value of R depends upon the maximum value of the d. c. input voltage, the maximum current rating of the regulator tube, and the expected maximum load current. The simplest way to determine its value in cases where the input voltage does not fluctuate greatly is by means of the following equation:

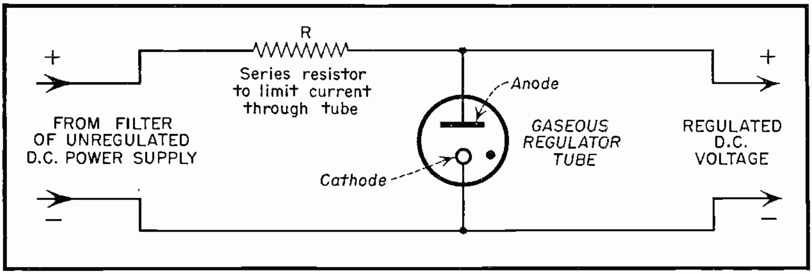

Fig. 1. Basic connection of gaseous regulator tube.

$$(1) \quad R = \frac{E_1 - E_2}{I}$$

Where R is the required resistance, in ohms

E_1 is the d. c. input voltage from the power supply filter

E_2 is the voltage rating of the gaseous regulator tube

I is the maximum current rating of the tube in amperes.

Consider a typical illustrative case in which 150 volts d. c. output regulated within 2 volts must be obtained from a 200-volt unregulated power supply. A type OD3 tube is selected, since the output voltage of this tube is 150 volts and its regulation control figure is 2 volts. The voltage rating (E_2) of this tube is 150; the maximum current rating of the tube is 40 milliamperes, or 0.04 ampere. From Equation (1), R = (200 — 150)/0.04 = 50/0.04 = 1250 ohms. The power which the resistor must dissipate is equal to I^2R = $0.04^2(1250)$ = 0 00016(1250) = 2 watts. For good safety factor, we would choose a 5-watt resistor. So R would be 1250 ohms, 5 watts.

When input-voltage fluctuations are large, it may be necessary to alter the resistance of R as determined by means of Equation (1), or it will be necessary to reduce the output load current. This is necessary because the voltage drop across a certain series resistor may be great enough to cause the tube to become extinguished when the input voltage falls to its minimum value. For instance, the starting voltage of the OD3 is 160 volts. A resistor which might satisfy the maximum input voltage conditions (that is, when the input voltage fluctuates to its highest value) will allow the glow to extinguish if the input voltage falls to 140. Thus, it is seen that the highest output current drains are possible only when fluctuations of the d. c. input voltage to the regulator tube are relatively small.

When higher output voltages than can be supplied by one gaseous regulator tube are required, several such tubes may be connected in series, as shown in Figure 2(A). Thus, two type OC3 tubes will regulate 210 volts (2 times 105 v.) and three type OB3's will regulate 270 volts (3 times 90 v.), etc., etc. The current through the series string will be the same number of milliamperes as stated for one tube. However, when tubes having different current ratings (such as 30 ma. for one and 40 ma. for the other) are series-connected, the maximum current through the series string must not exceed that specified for the lowest-current tube. Taps may be taken between any two tubes (See Figure 2-A) in order to obtain intermediate voltages.

When higher output currents are required than one gaseous regulator tube can supply, several such tubes may be connected in parallel, as shown in Figure 2(B). However, a 100-ohm resistor (R_2 and R_3 in Figure 2-B) must be connected in series with each tube in order to divide the current equally between the tubes. Higher resistances must not be used, since even the relatively low 100-ohm value reduces the regulation efficiency somewhat.

present in the powered circuit directly across the regulated d. c. output, their total capacitance must not exceed 0.1 microfarad, otherwise oscillation will take place. The reason for this oscillation is clear from an examination of Figure 1. If a capacitor is placed across the regulated-d. c. output terminals, a conventional relaxation-type oscillator circuit is formed by the tube, the capacitor, and resistor R.

4-Tube Regulated D. C. Power Supply

Figure 3 shows the circuit diagram of a voltage-regulated d. c. power supply which delivers an output voltage stabilized within 1 volt. This degree of stabilization holds for input voltage variations or output current (load) variations up to about 30 per cent of the initial values. A unit of this type should be used whenever the severity of requirements precludes use of simple gaseous regulator tubes.

In this circuit, the 6B4-G tube acts as a variable resistor in the d. c. out-

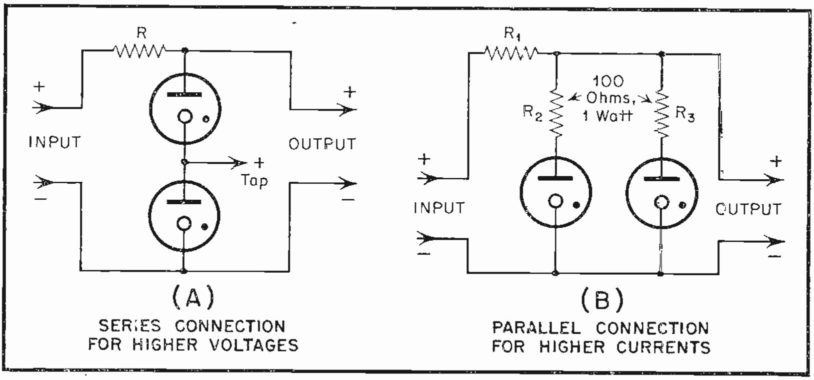

Fig. 2.

Oscillation is a common trouble experienced by many builders of gaseous-tube voltage regulators. This is caused by one or more capacitors in the load (output) circuit which the regulator supplies. When such capacitors are

put circuit of the filter. In this respect, it is an electronic rheostat. The plate resistance of the 6B4-G is controlled by the grid bias voltage of this tube which in turn is delivered by the 6SJ7 d. c. amplifier tube. If the d. c.

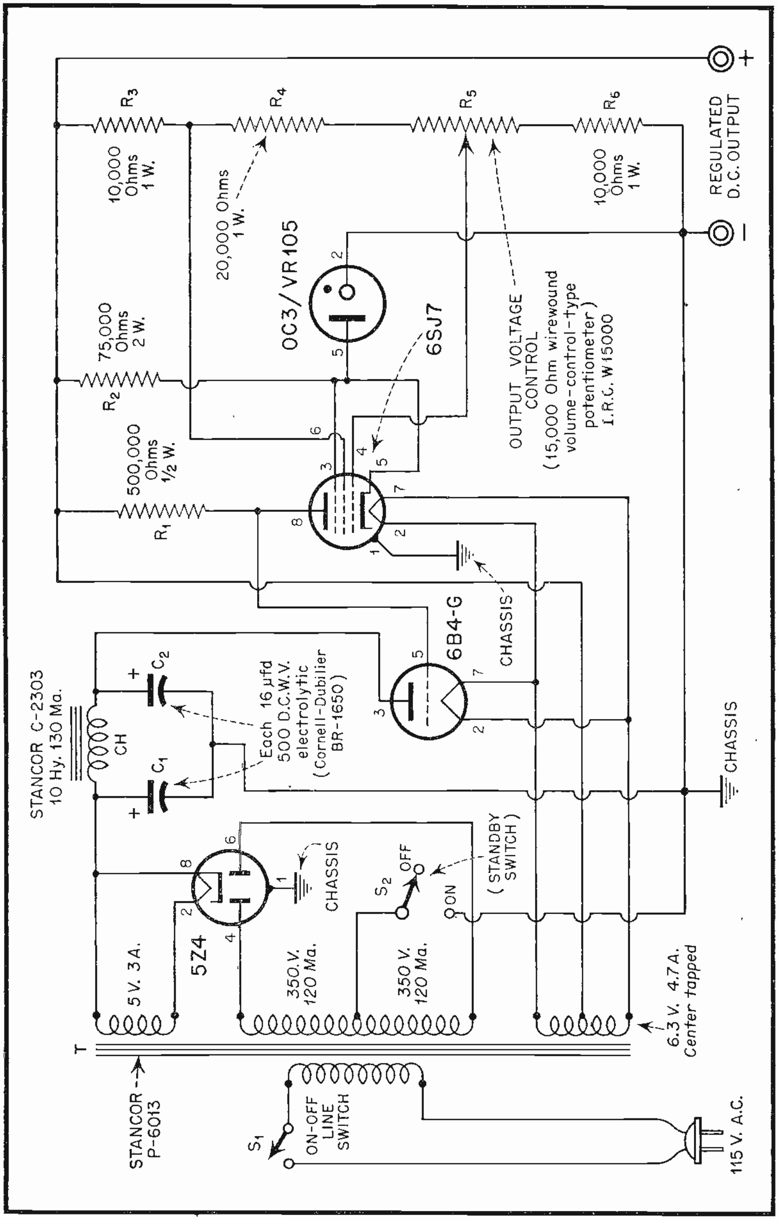

Fig. 3. Voltage-regulated d.c. power supply.

output of the entire system tends to fall in value, the bias on the 6B4-G will be decreased automatically. The plate resistance of the 6B4-G accordingly will decrease, permitting the output voltage to rise. Thus, any output voltage change bucks itself out.

The regulated output voltage may be set at any value between about 175 and 300 volts by means of the output-control potentiometer, R_5. At 300 volts, the current which may be taken from the output terminals with good regulation is approximately 60 milliamperes; at 175 volts, it is 110 ma.

Regulated power supplies having larger voltage and current output capabilities may be constructed along the same lines by employing a heavier-current rectifier tube than the 5Z4 and a larger control tube than the 6B4-G.

A. C. Voltage Regulation

Electronic circuits may be stabilized also by regulating the a. c. voltage input. In precision laboratory equipment where the highest order of stability is required, a. c. stabilization often is employed in addition to d. c. voltage regulation.

Perhaps the most satisfactory method of regulating a. c. voltage is to use one of the so-called regulator transformers. These units utilize the principle of core saturation and provide close regulation either of power-line voltage or of filament (heater) voltage. Regulator transformers are simple to use and may be built into the equipment which they supply. They are furnished for a wide variety of volt-ampere drain requirements. Althought voltage regulator transformers normally are rather high-priced, several useful models of various volt-ampere capacities are obtainable currently at reasonable prices in the surplus market.

Two other methods for a. c. voltage regulation are shown in Figure 4.

The first scheme (See Figure 4-A) employs two gaseous regulator tubes connected in parallel back-to-back between the a. c. power line and the primary winding of the transformer to be regulated. The resistance of R is

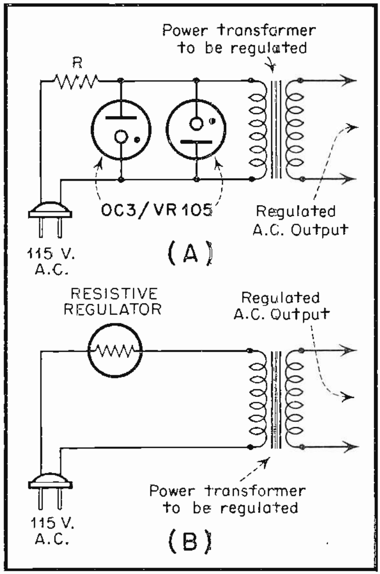

Fig. 4. Simple a.c. voltage regulators.

selected to have such a value as to limit the maximum current through both tubes to 80 milliamperes, while at the same time not being so high as to allow the tubes to deionize when the line voltage fluctuates to its minimum value.

The regulated voltage delivered to the primary of the transformer will, of course, be somewhat lower than the line voltage (being equal to the line voltage less the drop in resistance R). The transformer secondary turns must be increased therefore to give the same output as obtainable without the regulator, or the circuit it supplies must be modified to operate at a lower voltage.

This regulator can supply only a limited output current and accordingly is satisfactory only for light-drain instruments such as simple oscillators, v. t. voltmeters, etc.

The second type of a. c. voltage regulator, shown in Figure 4(B), utilizes a special resistance unit which nected into the power supply circuit, as an electronic series resistor, may be employed as a current regulator. Such an arrangement is shown in Figure 5(A).

The screen voltage and control grid (bias) voltage of the tube are proportioned so that the tube is operated

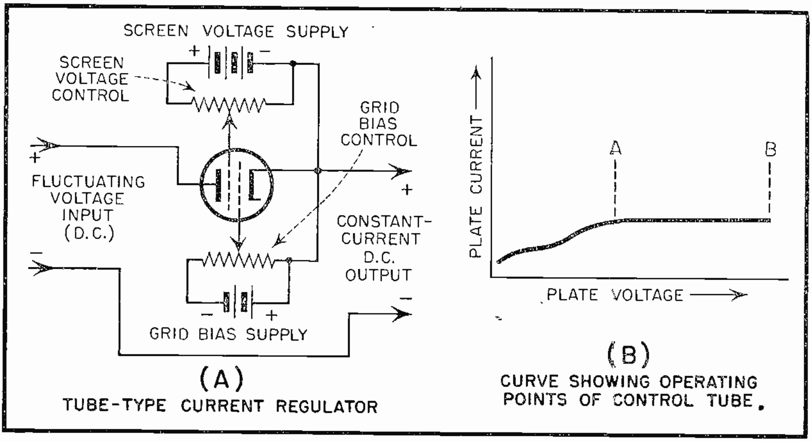

Fig. 5.

tends to iron-out voltage variations by maintaining a constant current through itself. These resistance units are known by various trade names, such as voltage regulators, voltage controls, and line ballasts. They are supplied in a variety of types to suit a wide range of power-drain requirements, and are obtainable as tube-type glass bulbs as manufactured by the Amperite Co. and as ventilated-metal-encased units as manufactured by the Clarostat, Wirt, Continental, Jackson, and other companies.

Simple Current Regulation

In some applications, d. c. voltage excursions can be tolerated but current must be held to a constant value. A pentode or beam tetrode tube, con-along the nearly straight, horizontal portion of its E_p-I_p characteristic curve (this is the region between points A and B on the sample curve in Figure 5-B. From the curve, it will be noted that the current changes only slightly as the voltage fluctuates between the wide limits set by points A and B.

A type 6L6 tube connected in the circuit shown in Figure 5(A) and operated at 50 screen volts and 0 control grid volts shows virtually no current variation between 200 and 500 volts.

While batteries are shown in Figure 5(A), the grid and screen voltages can be obtained from separate a. c.-operated power supplies or from taps on a suitable voltage divider in the power supply which is being regulated.