CHAPTER 33

CURRENT AND VOLTAGE REGULATORS

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SECTION 1 : CURRENT REGULATORS

(i) Barretters (ii) Negative temperature coefficient resistors (Thermistors).

(i) Barretters

In a.c./d.c. receivers, the valve heaters are wired in series and connected across the mains supply. If the total of the heater voltages is less than the mains voltage a current-limiting fixed resistor or a barretter is used in series with the heater circuit to absorb the extra voltage.

The disadvantage of the fixed resistor is that the current variations through the heater circuit are greater than if the circuit consisted of valve heaters alone.

See Chapter 35 Sect. 6 for the application of series resistors and barretters to a.c./d.c. receivers.

To maintain a constant current through the series heater circuit, with widely varying mains voltages, a barretter is generally employed. This consists of a hydrogen-filled tube containing an iron filament and has the property of nearly constant current flow for wide variations in voltage across it. The actual voltage limits between which satisfactory current regulation is obtained are stated by the manufacturers, and the barretters should be chosen with regard to these values.

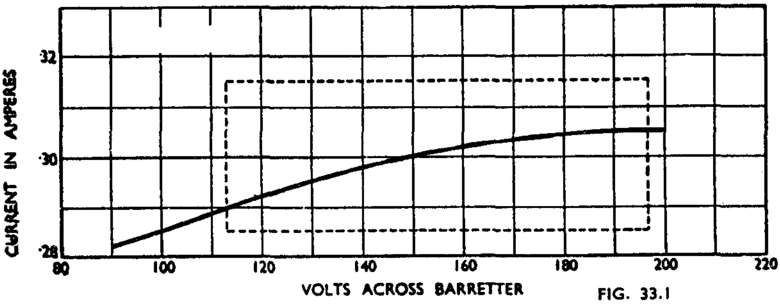


FIG. 33.1

Fig. 33.1. The characteristic of a typical barretter.

A typical barretter characteristic is shown in Fig. 33.1 ; the portion of the curve within the dotted rectangle showing the useful operating voltage range and the tolerances on the current regulated by the barretter.

It should be noted that the barretter is subject to a large surge current when switching on as the resistance of the valve heaters is then only about one seventh or one tenth of their hot (running) resistance.

In certain cases, a maximum total of heater voltage to be connected in series with the barretter is specified on the manufacturer's data sheets. This then protects the regulator against excessive surge currents which would shorten its life.

Owing to the iron filament, barretters should be kept well clear of any magnetic field which could damage them and for this reason a magnetic screen is sometimes used around them. As considerable power is dissipated in the barretter, the magnetic shield should be perforated and good ventilation provided. The barretter should always be operated in a vertical position, base down.

Occasionally it is desired to increase, by a small amount, the current controlled by a barretter and this may be done, within certain limits, by operating it in parallel with a fixed resistance. This is not normally recommended since the effectiveness of the barretter is reduced. It may be used fairly satisfactorily for an increase of current up to about 10% of the current in the barretter.

If the barretter is required to control a current which is smaller than its current rating, this may be accomplished by shunting the current-regulated device by a resistor to bring the total load current up to the normal barretter current.

As with any other device, a barretter has manufacturing tolerances, but these are such that if a design is based on an average sample then no damage is likely to be done to the valves with any individual barretter.

(ii) Negative temperature coefficient resistors (Thermistors)

These are described in Chapter 4 Sect. 9(i)n.

SECTION 2 : VOLTAGE REGULATORS

(i) Gaseous tube voltage regulators (ii) Valve voltage regulators.

In cases where stability of plate voltage supply is essential, some form of voltage regulation must be provided to prevent changes due either to mains input or load current variations.

(i) Gaseous tube voltage regulators

The electronic voltage regulator is shown in its simplest form in Fig. 33.2. In this circuit a gas-filled two electrode tube is used as the voltage regulator. The characteristics of this tube are such that quite large variations of current through the tube do not greatly alter the potential drop across it.

The circuit of Fig. 33.2 regulates the output voltage within certain interdependent limits of input voltage and load resistance. If the input voltage increases for constant load resistance or the load resistance increases for constant input voltage then in either case the voltage across R_L tends to increase. As E_R tends to rise, the regulator tube takes more current and increases the voltage drop across R_1, maintaining the voltage E_R at nearly its original value. The resistor R_1 is essential to obtain voltage regulation. Furthermore, as the striking voltage of the regulator tube is higher than its operating voltage, R_1 is necessary to prevent excessive tube current. Table 1 gives values of minimum supply voltages required for starting the regulator tube, together with starting and operating voltages of typical tubes.

Referring to Fig. 33.2, if E_{in} = input voltage and I_t = regulator tube current, the following equation holds

$$E_R = E_{in} - (I_L + I_t)\,R_1 \qquad (1)$$

The range of regulation or the maximum change in E_{in} or R_L within the region of regulation can be determined accurately for any conditions of operation by substituting in eqn. (1) the limits of the variables E_{in}, I_L, I_t, R_L. The regulator tube must operate between the published limits of current rating. The change in one of the variables E_{in}, or R_L, can be much greater than in the other and when one of these changes is small the approximate range of regulation can be simply obtained by considering either E_{in} or R_L constant. If these conditions apply and E_R is constant it follows by equating the partial differentiations of eqn. (1) to zero

that $$\frac{\triangle E_{in}}{E_{in}} = \frac{R_1 \triangle I_t}{E_{in}} \qquad (R_L \text{ constant}) \qquad (2)$$

and $$\frac{\triangle I_L}{I_L} = -\frac{\triangle I_t}{I_L} \qquad (E_{in} \text{ constant}) \qquad (3)$$

where $\triangle E_{in}$, $\triangle I_L$, $\triangle I_t$ are the small increments in E_{in}, I_L, I_t. The range of regulation is obtained by inserting in these equations the maximum value of $\triangle I_t$.

TABLE 1

Regulator Tube Type	Approximate Operating Voltage	Approximate Starting Voltage	Minimum Supply Voltage
OA2 (miniature)	150	160	185
OA3	75	100	105
OB2 (miniature)	108	115	133
OC3	105	115	133
OD3	150	160	185

Operation about the midpoint of the type OD3 characteristic gives $\triangle I_t$ (max.) $=$ $(40 - 5)/2 = 17.5$ mA. Consider the regulator subject to small changes in load. If for example $I_L = 175$ mA, from eqn. (3) the range of regulation $\triangle I_L/I_L = 17.5/175 = 10\%$. Equation (2) shows that a large range of regulations with variable E_{in} is obtained when R_1 is large, i.e. when a large part of E_{in} appears across R_1.

When small load currents are required and variations in E_{in} and R_L are small, satisfactory regulation can be obtained by operating the regulator tube at low average current.

Regulation is frequently desired when R_L varies over the very large range from no load to full load. In this case R_1 is adjusted so that at no load the maximum tube current at maximum input voltage does not exceed the tube's rating, i.e., 40 mA for type OD3. Load voltage regulation is then obtained from zero load current to nearly 35 mA if changes in E_{in} are small.

The tube voltage of types OD3, OC3 can change over their operating range by approximately 3% and this represents their limit of regulation under wide range conditions.

If higher regulated voltages are required two or more tubes can be connected in series as in Fig. 33.3. Additional stabilized voltages may be taken off the individual tubes as shown. Tapping points may be provided on R_{L2} to give lower voltages, however if the load varies, good regulation will be obtained only if the current drawn from the tapping point is very small compared with the current through R_{L2}. Grid bias supplies for class A amplifiers may be effectively stabilized by the circuit of Fig. 33.2 with tappings as required—see chapter 13 Sect. 10(ii).

The use of gaseous regulator tubes in parallel is not to be recommended as resistors must be put in series with each tube so that all tubes will start and share current equally. These resistors impair voltage regulation. Therefore when large currents have to be handled, grid controlled valve voltage regulators must be used.

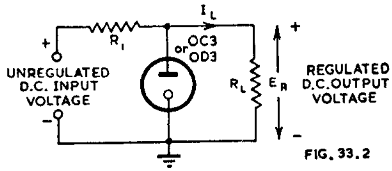


FIG. 33.2

Fig. 33.2. *Simplest form of gaseous tube voltage regulator.*

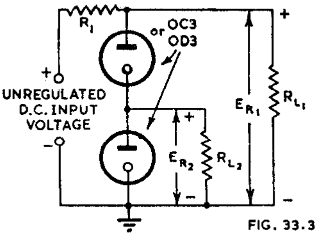


FIG. 33.3

Fig. 33.3. *Higher regulated voltage provided by two gaseous tubes in series.*

(ii) Valve voltage regulators

A typical valve voltage regulator is shown in Fig. 33.4. The valve V_1 acts as a variable resistance whose value is varied by a change in bias. When the output voltage tends to decrease, the grid voltage of V_2 becomes less positive. As the cathode voltage and positive with respect to the grid, the fall in the positive value of the grid will increase the negative bias on the valve, and I_b will decrease. This decrease of plate current will cause an increase in the voltage at the plate of V_2. The plate of V_2 being directly connected to the grid of V_1 will cause a drop in the negative bias on V_1 and the plate-cathode voltage will decrease, tending to restore the original voltage drop across E_R.

The complete mathematical analysis of voltage regulator performance is fairly complex and for detailed information reference should be made to the bibliography at the end of this chapter.

For practical purposes of voltage regulator design, the following method may be used.

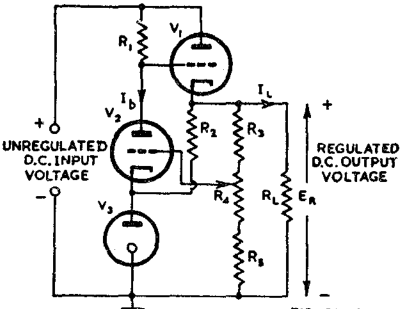


FIG. 33.4

Fig. 33.4. *A typical valve voltage regulator.*

Referring again to Fig. 33.4. If constant output voltage is to be maintained across the load, the valve V_1 must be capable of adjusting its voltage drop to compensate for voltage input changes. A similar condition exists if the input voltage is constant and variable output voltage is required. The valve has therefore to satisfy conditions at four points as set out in Table 2.

TABLE 2

Point	Output	Valve V_1	
		Plate Voltage	Plate Current
1	Maximum Voltage Maximum I_L	Supply Voltage Maximum Output Voltage	Maximum I_L
2	Maximum Voltage Minimum I_L	Supply Voltage Maximum Output Voltage	Minimum I_L
3	Minimum Voltage Maximum I_L	Supply Voltage Minimum Output Voltage	Maximum I_L
4	Minimum Voltage Minimum I_L	Supply Voltage Minimum Output Voltage	Minimum I_L

Each of these four points has its particular limitations as regards the operation of the valve to maintain the correct operating conditions without exceeding the maximum ratings. Reference should be made to Fig. 33.5 in which these four points are plotted for a triode-connected type 807 valve.

Point 1—this point must be kept in the negative grid-bias region of the curve and a bias of not less than −3 volts may be taken as the design minimum. This point must also be kept below the maximum plate or screen dissipation curve (whichever is first reached), and below the recommended value of current for a steady d.c. oper-

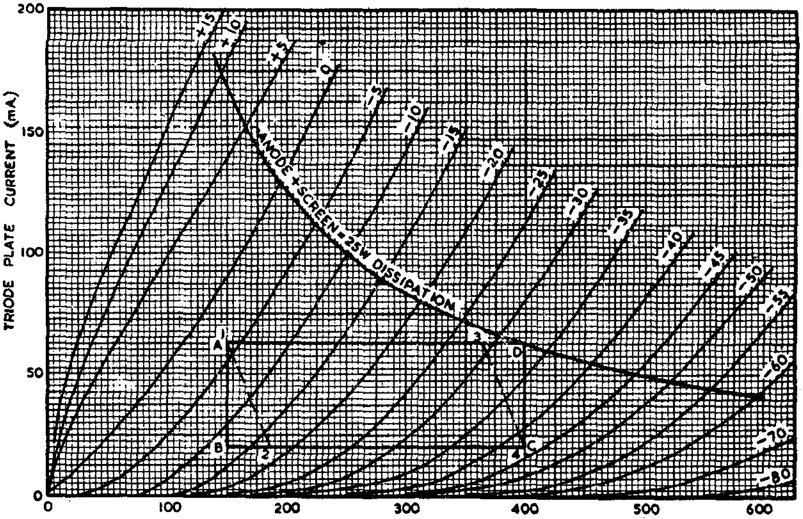


FIG. 33.5

Fig. 33.5. Plate characteristics of triode-connected 807 valve to illustrate operation of the valve as a voltage regulator.

ting condition. It is important that point 1 be kept above a certain minimum value of plate voltage if linear characteristics are to be obtained from V_1, a value of not less than 125 volts on the plate being recommended.

Point 2—In order that this point should not come in the non-linear portion of the plate characteristics, a bleed should be arranged across the supply to limit the minimum current. This also aids power supply regulation (see Chapter 30 Sect. 3).

Point 3—This point should be kept below the maximum dissipation curve and below the maximum rated plate voltage for the valve being used.

Point 4—This point should be kept above the non-linear portion of the characteristics by means of a bleed as in (2) and also kept below the maximum plate voltage value for the valve being used.

The maximum recommended usable section of the valve characteristic for type 807 is shown enclosed by ABCD in Fig. 33.5.

While it is possible to use higher plate current values at low plate voltages than appear in the diagram before the plate dissipation is exceeded, this is not to be recommended as reduced valve life may result.

From the graphical construction can be seen the effect of large variations of input voltage to the regulator with varying output currents (i.e. poor regulation of the power supply). This will cause the point 2 to move along the plate voltage axis, which results in a reduction of the maximum variation of output voltage obtainable. When the power supply has good regulation and the input voltage is substantially constant, an output variation of ± 125 volts is obtainable about a nominal value. With a constant output voltage the same tolerances may be allowed in the input voltage i.e. ± 125 volts. In each case it is assumed that the circuit conditions are set so that the valve is operating at its centre point for the nominal input or output voltage.

It will be seen from this description that a choke input power supply is advisable. Reference should be made to Chapter 30 Sect. 3 for further information on choke input power supply design.

For minimum voltage loss across V_1 a valve with a high g_m should be used. If the load current required from the regulated supply is greater than that obtainable with one series valve, then two or more valves may be placed in parallel.

TABLE 3

Valves suitable for use as series regulators.

Valve type	Current (mA)
6F6-G*	45
6V6-GT*	50
6L6-G*	80
6Y6-G*	80
807*	80
6AS7-G	250

*Screen connected to plate through 500 ohm 1 watt resistor.

Having now determined the operating conditions for V_1, the design may be extended to consider the operating conditions for the amplifier valve V_2.

From the knowledge of the voltage drop in V_1 required for the four operating points, the corresponding bias values can be determined. The voltage drop across the resistor R_1 is then given by the voltage drop across V_1 plus the required grid bias for V_1.

Having determined these voltages, the resistance R_1 can be chosen to have a value which will give plate current values for the amplifier valve which are on the linear portion of its plate characteristics.

The higher the gain of V_2, the better will be the regulation, as a smaller change in output will be effective in adjusting the voltage drop across V_2 to correct the output voltage change. For this reason a pentode is recommended, the additional complication of adding a screen supply being small for the improvement obtained.

In general, the plate voltage for V_2 should be derived, through its plate load resistance R_1 from the input voltage to the regulator, so that even at low output voltages not less than the minimum voltage drop of V_1 plus its grid bias voltage will exist across R_1. The exception to this connection will be when the output voltage of the regulator is to be constant at a value of 200 or greater and the input voltage is to be varying over wide limits ; the effect of connecting R_1 to the input in this case would be to reduce the effective gain of the valve.

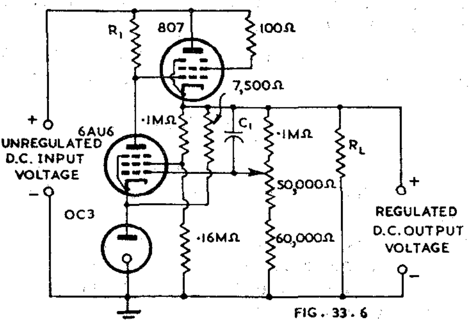


FIG. 33.6

Fig. 33.6. *Simplest form of series valve voltage regulator.*

The connection of the gaseous voltage regulator tube V_3 also requires some consideration. It has been mentioned in Sect. 2(i) that changing the current through a voltage regulator tube will produce a small change of voltage across it. As this tube is used as the reference voltage for the regulator, any change in potential across it will have an adverse effect upon the regulator performance. For this reason, if a constant output voltage regulator is being designed, the series feed resistor for this tube should be supplied from the output side of the regulator, the extra current drawn by this tube being taken into account when considering the current rating for V_1. In cases where the regulator has to supply varying output voltages, V_3 may be supplied from the input if this is sufficiently constant ; preferably, V_3 should be supplied from a separate source.

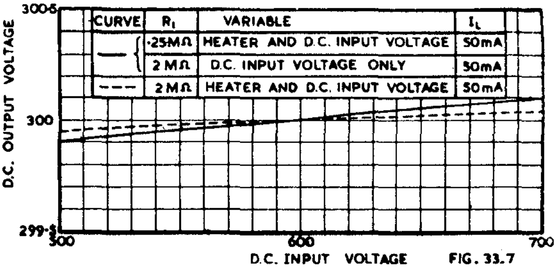


FIG. 33.7

Fig. 33.7. *Operation characteristics of circuit Fig.* 33.6—*output versus input voltage.*

Circuits of typical voltage regulators and their performance figures are given in Figs. 33.6 to 33.14.

In Fig. 33.6 is shown the simplest form of series valve voltage regulator, which, however, with the circuit components and values shown, is capable of good performance. The results obtained with this regulator are shown in Figs. 33.7 and 33.8, from which several points should be noted. The variation of heater voltage as well as the input direct voltage, the usual practical case, results in better regulation than that obtained with only direct voltage changes. This is due to a slight change of plate current in V_2 together with other minor circuit changes caused by the variation of cathode temperature in the valves. For rapid input voltage changes the regulation characteristic will be as for direct input voltage changes only since the cathode temperature cannot change rapidly. A value of 250 000 ohms for R_1 will be found to be sufficient for most purposes as little increase in gain is obtained by increasing R_L above this value.

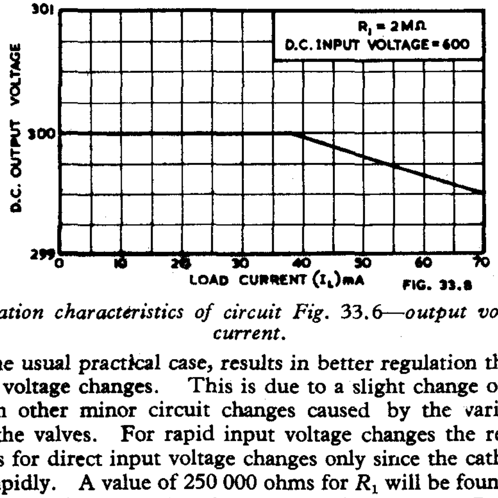


FIG. 33.8

Fig. 33.8. *Operation characteristics of circuit Fig.* 33.6—*output voltage versus load current.*

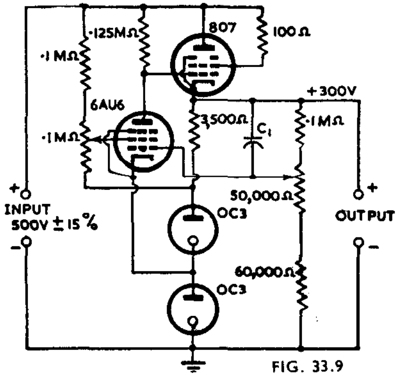


FIG. 33.9

Fig. 33.9. *Valve voltage regulator in which the screen is used to correct for input voltage changes.*

Such a value will allow this resistor as well as all others to be wire wound if particularly stable operation is required.

No advantage is gained in the circuit of Fig. 33.6 in stabilizing the screen supply, this already being supplied from a substantially constant source. However screen stabilization is necessary when the screen is used to correct for input direct voltage changes A circuit of this type is shown in Fig. 33.9 and a constant or overcorrected output is obtainable.

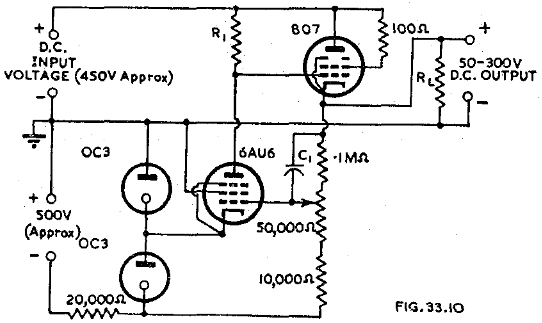


FIG. 33.10

Fig. 33.10. *Valve voltage regulator with a controllable output voltage.*

The circuit of Fig. 33.10 is useful where a controllable output voltage is required and is suitable for output voltages from 50 to 300. Regulation characteristics for this regulator are shown in Figs. 33.11 and 33.12.

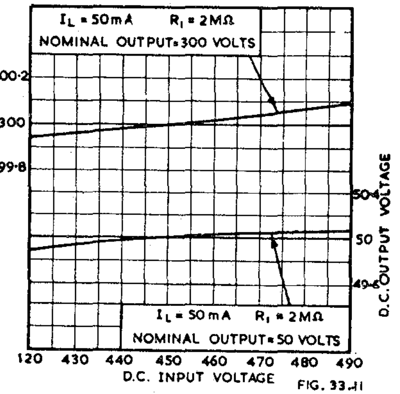


FIG. 33.11

Fig. 33.11. *Regulation characteristics for circuit of Fig.* 33.10—*output versus input voltage.*

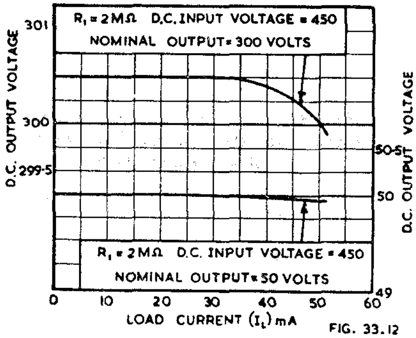


FIG. 33.12

Fig. 33.12. *Regulation characteristics for circuit of Fig.* 33.10—*output voltage versus load current.*

To draw a constant value of bleed current from the variable voltage supply, in order to prevent soaring of the output voltage on no load, some form of constant current device must be used. Refer to explanation of points 2 and 4 under Table 2. A suitable circuit is shown in Fig. 33.13 in which a 6V6-GT type valve is used as a constant current pentode ; with plate voltages from 50 to 300 the plate current will only vary from 18.5 to 19.0 mA.

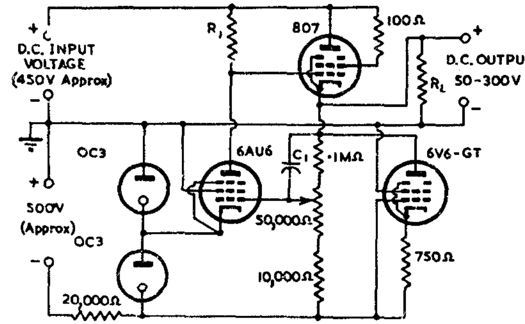
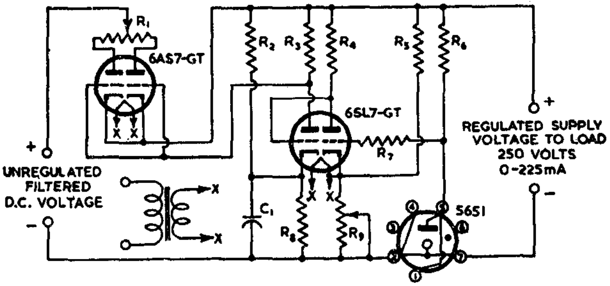


FIG. 33.13

Fig. 33.13. Valve voltage regulator with a controllable output voltage as Fig. 33.10 but including constant current pentode to draw constant bleed current for varying output voltages.

The condenser C_1 in all circuits assists in the reduction of ripple from the regulated supply as the grid of V_2 then obtains the full ripple voltage from the supply instead of the fraction determined by the values R_3, R_4 and R_5 (Fig. 33.4). This condenser should have a value not greater than that required for satisfactory ripple suppression as large values will cause a time lag in the operation of the output voltage control, a value of .01 to .1 μF being satisfactory for most purposes.

The need for negative voltage supplies for several of the given circuits need not require the addition of a separate power supply ; reference should be made to Chapter 30 Sect. 6 which gives details of shunt diode bias supplies which would be suitable for this purpose. The regulator tube current in typical circuits, except Fig. 33.14,



C_1 = 0·1μF, 400V
R_1 = Plate current balancing potentiometer 160Ω, 10W
R_2 = 12,000Ω, 2W
R_3 = ·47MΩ, ·5W
R_4 = ·47MΩ, ·5W
R_5 = 12,000Ω, 2W
R_6 = 68,000Ω, 1W
R_7 = 1MΩ, ·5W
R_8 = 15,000Ω, 2W
R_9 = Output voltage-control potentiometer 10,000Ω

FIG. 33.14

Fig. 33.14. Voltage regulator utilizing a special voltage reference tube (type 5651) to give extremely good voltage regulation.

may be adjusted to have a value of approx. 10 mA at the normal operating point of the regulator.

For most applications these circuits will give adequate regulation but for details on compensated and the more complicated regulators reference should be made to the bibliography at the end of this chapter.

The main limitation of all these regulators is the difficulty of obtaining a completely stable reference voltage, as gaseous voltage regulator tubes may stabilize at slightly different voltages when the unit is switched off and on again. This means that, although nearly perfect voltage regulation may be obtained, the voltage about which this regulation takes place is not always a constant value.

This defect may be minimized by the use of a special voltage reference tube such as R.C.A. type 5651 as, for example, in the circuit of Fig. 33.14. The unregulated input is approximately 375 volts at zero load current and 325 volts at 225 mA load current. The variation of output voltage is less than 0.1 volt for a variation of ± 10% in input voltage when operated at maximum load current. When adjusted to an output of 250 volts, the variation in output voltage is less than 0.2 volt over the current range from 0 to 225 mA.

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Additional references will be found in the Supplement commencing on page 1475.