TABLE II. Tests for dependence of resistance upon measuring current.

Sample No.	Temperature °K	Approximate current amp.	Resistance ohms
3	4.215	3.4×10^{-6}	22,960
		2.8×10^{-4}	22,918
		3.4×10^{-6}	22,964
	1.253	2.4×10^{-6}	41,660
		1.6×10^{-4}	41,585
		2.4×10^{-6}	41,655
5	4.215	1.8×10^{-6}	63,150
		1.0×10^{-4}	62,960
		1.8×10^{-6}	63,160
8	77.3	1.8×10^{-6}	22,998
		2.8×10^{-4}	23,000
		1.8×10^{-6}	23,008
9	77.3	2.3×10^{-6}	59,090
		1.1×10^{-4}	59,130
		2.3×10^{-6}	59,100

+0.015° at 4.215° K and +0.004° at 1.25° K. For sample No. 5 the effect at 4.215° K corresponds to +0.003° K. For sample No. 9 at 77° K, the effect is in the opposite direction to that produced by a slight heating of the sample and probably represents a real deviation from Ohm's law. The resistances of samples Nos. 8 and 9 were too large at helium temperatures to permit accurate tests. (See Table II.)

We believe these few data to be sufficiently promising to warrant further study of resistances comparable to samples Nos. 2, 3, 4 and 5.

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Improving Differential Amplifier Rejection Ratios*

RICHARD MCFEE
Heart Station, University Hospital, Ann Arbor, Michigan

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A LARGE number of circuits having the differential amplifier property are known, but of these only a few have combined simple construction and operation with stable, high rejection ratios. The most important differential amplifiers are shown in Fig. 1.[1] The purpose of this note is to describe for two of these circuits some simple modifications which result theoretically in infinite rejection ratios and experimentally in rejection ratios about fifty times as great as those of the unmodified circuits. By using adjustable potentiometers in these modified circuits, their rejection ratios may be made as large as desired.

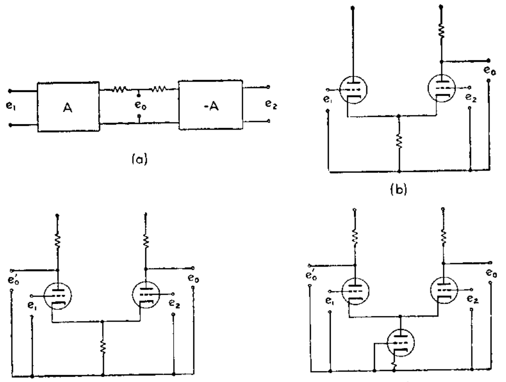

FIG. 1. Basic differential amplifier circuits.

Modification A: The first modification is shown in Fig. 2 and is obtained from the circuit of Fig. 1(b) by adding the resistor R_s. Several factors act to make the output of a modified circuit insensitive to the common-mode component of the input. There is degeneration due to cathode-follower action which reduces the effective grid voltage resulting from the common-mode component to about two percent of its actual value, and there is complete cancellation of the amplified residual e_g at the output, as can be seen from the equivalent circuit. Thus, the common-mode gain is zero, and the rejection ratio infinite. This property of the circuit is dependent only upon tube balance and equality of the cathode and shunt resistors; it is independent of the impedance of the load and the linearity of the tube characteristics.

Because tubes and resistors are in reality never precisely matched, the common-mode gain will not be exactly zero. Experimental tests indicate that using ±1 percent tolerance resistors and randomly selected 6SL7's rejection ratios from 2000 to 4000 may be expected. Of course when the d.c. plate voltages of the tubes are not the same it is necessary to change either R_s or R_k slightly to compensate for the resulting unbalance in tube gains and plate resistances, but this correction need not be variable. If a very high rejection ratio is desired, a balancing potentiometer may be added as is shown in Fig. 2(c).

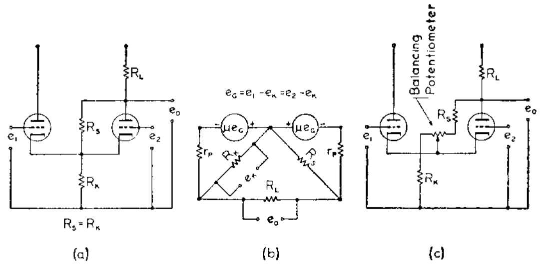

FIG. 2. Modification A. (a) Circuit. (b) Equivalent circuit. (c) Circuit with balancing potentiometer.

The gain of the circuit is

$$\frac{e_0}{(e_1-e_2)}=\frac{\mu R_T}{r_p+R_T},\quad R_T=\frac{R_kR_L}{2R_k+R_L}. \tag{1}$$

In the actual design of the circuit it is desirable to choose R_k and R_L so that the gain is maximum for a given tube voltage, current and plate supply voltage. It can be shown that this will occur when the d.c. voltage across the cathode resistor is one-half the total supply voltage. This condition completely determines the values of the resistors.

It is sometimes useful, in designing the circuit for use without a balancing potentiometer, to be able to calculate the common-mode gain resulting from unbalances in tube gains. An approximate equation for this is

$$\frac{e_0}{\frac{1}{2}(e_1+e_2)}=2\frac{\mu_1-\mu_2}{\mu_1+\mu_2}. \tag{2}$$

Similar equations showing the effect of mismatches in tube plate resistances and circuit resistances have been worked out.

Modification B: The second modification[2] is shown in Fig. 3 and is obtained from the circuit of Fig. 1(c) by adding the two pairs of resistors R_1 and R_2 and the resistor R_c. Zero common-mode gain results partly from cathode-follower degeneration and partly from the cancellation of the amplified residual by the bucking resistors R_2 connected from the cathode to the output. Complete cancellation occurs when

$$\frac{R_2}{R_1}=\frac{R_L}{2R_k}. \tag{3}$$

The magnitude of R_c does not affect the differential action of the circuit. It is determined by the desired tube voltages and currents, the values of the other resistors, and the plate-supply voltage.

With ±1 percent tolerance resistors and 6SL7's, rejection ratios from 2000 to 5000 are found. When an even higher rejection is desired, a balancing potentiometer may be located as is shown in Fig. 3(c).

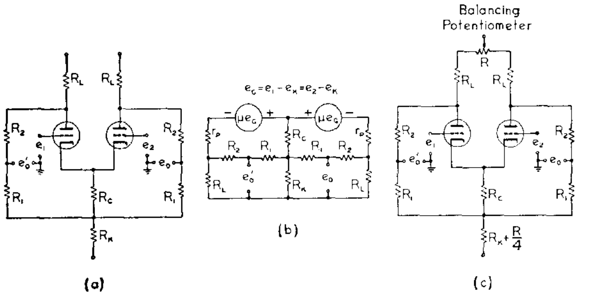

FIG. 3. Modification B. (a) Circuit. (b) Equivalent circuit. (c) Circuit with balancing potentiometer.

An equation for the gain is

$$\frac{e_0}{(e_1-e_2)}=\frac{R_1}{R_1+R_2}\frac{\mu R_T}{r_p+R_T}, \quad R_T=\frac{(R_1+R_2)R_L}{R_1+R_2+R_L}. \tag{4}$$

An approximate value for the common-mode gain resulting from unbalance in tube amplification factors may be found using Eq. (2).

This circuit may be used as a differential d.c. amplifier, but it is advantageous to do so only when one stage of amplification is required, or when a single-ended output is needed. It might be noted that when $R_1=R_2$, the output is at the d.c. level of a center-tap on the plate power supply, which can be grounded. In this case the output is not affected by equal changes in the tube characteristic or emission, or by variations in the plate voltage.

Both of these circuits may be used as multipliers. Large variations of the common-mode voltage will not affect the output directly but will vary the differential gain if the tubes are non-linear, and this variation of gain is easily used to obtain multiplication. They may also be used as simple balanced modulators.

The author is indebted to Dr. Samuel Seely of the Syracuse University Electrical Engineering Department for help in checking the equations.

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[1] Differential amplifiers are discussed comprehensively in Valley and Wallman, "Vacuum Tube Amplifiers," MIT Radiation Lab. Series No. 18 (McGraw-Hill Book Company, Inc., New York, 1948), pp. 441–451.

[2] The author has learned that this circuit has been used by Dr. W. A. H. Rushton of Cambridge University, although details concerning it have not been published.

Voltage Stabilizer for 200 Kv Acceleration

J. T. DEWAN
Atomic Energy Project, National Research Council of Canada, Chalk River, Ontario, Canada

May 8, 1950

IN recent experiments with the resolved beam from a 200 kv positive ion accelerator[1] it was necessary to prevent the beam from wandering more than 0.5 mm on a target placed 100 cm from the exit face of the 90° resolving magnet. This required the accelerating voltage to be held constant to 0.1 percent despite fluctuations of 1 percent in the a.c. supply voltage.

A stabilization ratio of 40 is achieved by the method shown schematically in Fig. 1. This method is an extension of the common degenerative stabilizer[2] and is somewhat similar to that used by Parratt and Trischka[3] for stabilizing voltages up to 50 kv. Regulation is effected by a series tube capable of handling variations of several thousand volts. This is controlled by a feed-back amplifier which receives as its error signal the difference between the voltage across a small portion of the 250 megohm bleeder resistance and a stable balancing voltage. The over-all voltage constancy depends on the stability of the bleeder chain which is a precision wire-wound resistance[4] guaranteed to 0.1 percent. Power is supplied to the stabilizer from a 500 c.p.s. generator which feeds the ion source and focusing supply at the d.c. level designated *G* in Fig. 1.

Essentials of the regulating circuit are shown in Fig. 2, all supply voltages being referred to the cathode of the stabilizer tube. A small fraction of any output voltage variation appears across R_1, is amplified in two stages directly coupled through Type 5651 high stability neon tubes, and the amplified voltage applied to the grid of a Type 4E27 series regulating tube. As the accelerator voltage is raised from 0 to 200 kv the voltage across R_1 increases from 0 to 160 volts. Consequently a stable adjustable bucking voltage is applied, via the 6AC7 cathode follower, to allow operation of the first amplifier grid at the correct d.c. level. The magnitude of the balancing voltage is controlled by a helical potentiometer which is operated through selsyn motors from the main control panel. The stabilizer is brought into proper operation at any given accelerating voltage by simply adjusting the potentiometer until the electrostatic voltmeter across the 4E27 tube indicates 3 to 4 kv. Fluctuations in the meter up to several kv in magnitude then represent the input voltage variations which are being canceled by the stabilizer tube. In order to protect this tube and the meter from overvoltage a 6H6 diode clamp is placed at the grid of the tube. This prevents the grid being driven negative by more than 105 volts and therefore prevents the plate voltage from rising above 7 to 8 kv. The exact voltage at which the plate clamps depends on the plate current which, however, varies only between 0 and 1 ma.

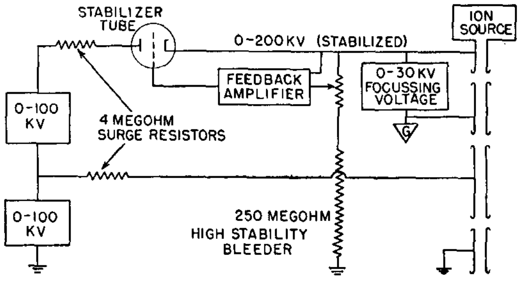

FIG. 1. Schematic diagram of the method of stabilization.

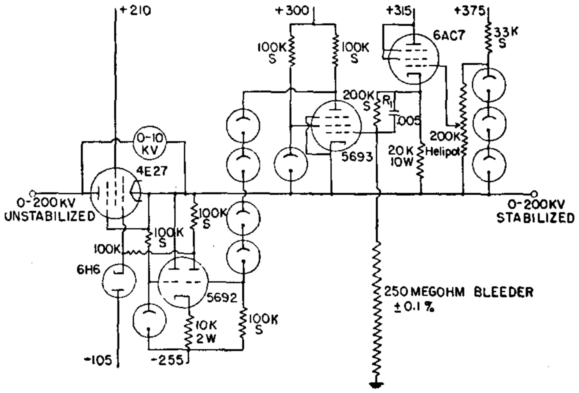

FIG. 2. Details of the stabilizer circuit. All neon tubes are Type 5651 and all resistances marked *S* are Nobleloy high stability 1-watt resistors.

Theoretically the stabilizer should reduce input voltage variations by a factor approximately equal to $\mu\beta G$ where μ is the amplification factor of the 4E27 tube (150), β is the feed-back factor (1/1250) and *G* is the gain of the amplifier (500). Thus the stabilization ratio should be 60 but in practice it is about 40. The reduction, inconsequent in this application, is caused by pick-up of stray radiation from the r-f ion source in the feed-back amplifier. With regulation, the output impedance of the accelerator is 10^6 ohms but variations in current at any given voltage are less than 10^{-4} ampere; hence fluctuations due to the high output impedance are only a few volts.