# VACUUM TUBE AMPLIFIERS


*Edited by*

GEORGE E. VALLEY, JR.

ASSISTANT PROFESSOR OF PHYSICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

HENRY WALLMAN

ASSOCIATE PROFESSOR OF MATHEMATICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY



OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE

*NEW YORK · TORONTO · LONDON*
*McGRAW-HILL BOOK COMPANY, INC.*
1948

desired. Also, when a quick current response in spite of load inductance is required, it is preferable to use the plate circuit. In this case, the current through the load tends to follow the grid voltage without being influenced by the voltage across the load as much as it would be if the load were in the cathode circuit.

If a pentode differential amplifier, where $\mu$ and $r_p$ are almost infinite, is used as an output circuit, Eq. (70) reduces to

$$\frac{\Delta i_L}{\Delta(e_1 - e_2)} = -\frac{g_m}{2 + \dfrac{R_L}{R_p}}. \tag{71}$$

Twice as much current gain can be realized if the load is divided into two parts, as in the case of a differential relay or a magnetic oscilloscope, where each of the two parts is simply one of the $R_p$'s and the output is the difference between these currents. For a pair of triodes, this output current is [adding $R_p$ to $r_p$ in Eq. (61)]

$$i_1 - i_2 = \frac{\mu}{r_p + R_p}(e_1 - e_2). \tag{72}$$

In the case of a pair of pentodes, the load resistance does not decrease the gain, and Eq. (66) applies directly.

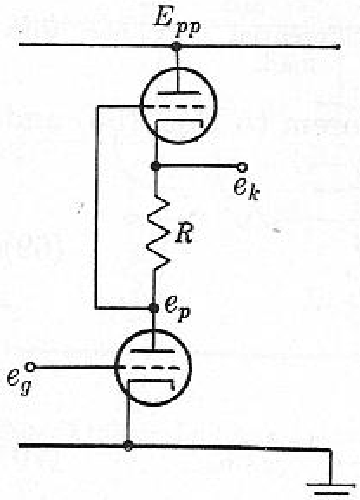

FIG. 11·37.—Series amplifier.

*Two-tube Series Arrangement.*—The circuit of Fig. 11·37, where $e_k$ is the output voltage, is sometimes useful as a power amplifier. A similar circuit, having another resistor equal to $R$ in series with the lower cathode and with the output terminal at $e_p$, affords cancellation of heater-voltage variation and is described in Sec. 11·12. The circuit between $E_{pp}$ and $e_p$, comprising the plate load for the lower tube, resembles the constant-current circuit of Fig. 11·18, but without the battery it is not actually a constant-current device. It is merely the equivalent of a simple resistance, of value $r_p + (\mu + 1)R$, returned to $E_{pp}$. Thus in Fig. 11·37 the voltage gain to the $e_p$ terminal is

$$\frac{\Delta e_p}{\Delta e_g} = \frac{-\mu[r_p + (\mu + 1)R]}{2r_p + (\mu + 1)R}. \tag{73}$$

Since all the current flows through $R$, the cathode is at a point at a distance $R$ from the $e_p$ end of the total equivalent resistance $r_p + (\mu + 1)R$, and therefore $e_k$ moves $\dfrac{r_p + (\mu + 1)R - R}{r_p + (\mu + 1)R}$ times as much as $e_p$. Thus, the gain to the cathode (with no load) is

$$\frac{\Delta e_k}{\Delta e_g} = \frac{-\mu(r_p + \mu R)}{2r_p + (\mu + 1)R}. \tag{74}$$

To find the gain with a load, it is easiest first to determine the current gain in the case of a zero-resistance load. If $R_L$ is zero in Fig. 11·38, so that $e_k$ is fixed at $E$, a change $\Delta e_g$ will produce a plate current increment $\Delta i_{p1}$ of $\mu\, \Delta e_g/(r_p + R)$. This increment, in turn, lowers the upper grid by a voltage increment $R$ times this, so that the upper tube current changes by an amount $\Delta i_{p2}$, equal to $-\mu^2 R\, \Delta e_g/r_p(r_p + R)$. Thus, if $R_L = 0$, the net current gain is

$$\frac{\Delta i_L}{\Delta e_g} = -\frac{\mu}{r_p + R} - \frac{\mu^2 R}{r_p(r_p + R)} = -g_m \frac{r_p + \mu R}{r_p + R}. \tag{75}$$

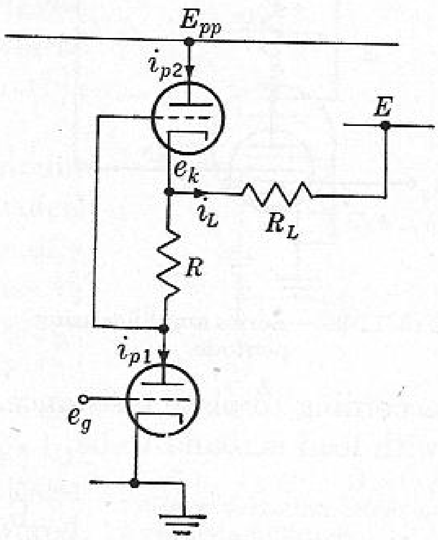


FIG. 11·38.—Series amplifier with load.

The current gain with a load of negligible resistance, where a suitable intermediate voltage source exists for a load tie point, is considerably greater than that for a simple amplifier or a differential amplifier or cathode follower.

The output impedance is the ratio of open-circuit voltage gain to short-circuit current gain.

$$Z_0 = r_p \frac{r_p + R}{2r_p + (\mu + 1)R}. \tag{76}$$

From Eq. (74), by means of Thévenin's theorem, the voltage gain with any load resistance is found to be

$$\mathcal{G} = \frac{-\mu(r_p + \mu R)}{2r_p + (\mu + 1)R + (r_p + R)\dfrac{r_p}{R_L}}. \tag{77}$$

The current gain with any $R_L$ is

$$\frac{\Delta i_L}{\Delta e_g} = -g_m \frac{r_p + \mu R}{r_p + R\left[1 + (\mu + 1)\dfrac{R_L}{r_p}\right] + 2R_L}. \tag{78}$$

It is apparent from Eq. (78) that as long as $R_L$ is considerably smaller than $r_p$, $R$ may be chosen so that the current gain is several times $g_m$. The maximum range of output current in both positive and negative directions is achieved with $E = E_{pp}/2$ and $R = 1/g_m$, but the maximum gain occurs with an $R$ of several times $1/g_m$.

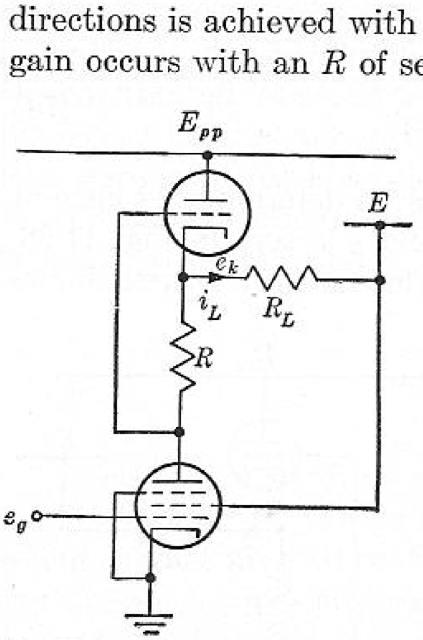


FIG. 11·39.—Series amplifier using pentode.

If a pentode is used in the lower position, as in Fig. 11·39, the formulas are simpler. In this case, Eq. (74), the voltage gain with $R_L = \infty$, becomes

$$\frac{\Delta e_k}{\Delta e_g} = -g_m(r_p + \mu R), \tag{79}$$

where $g_m$ refers to the pentode and $\mu$ and $r_p$ to the triode. The output impedance is simply

$$Z_0 = r_p, \tag{80}$$

because the pentode current is independent of its plate voltage, so that if $e_k$ is moved by external means, the triode bias will remain constant and its current will vary according to plate resistance. From Eqs. (79) and (80) the voltage gain with load is found to be

$$\mathcal{G} = -g_m \frac{r_p + \mu R}{1 + \frac{r_p}{R_L}}, \tag{81}$$

and the current gain is

$$\frac{\Delta i_L}{\Delta e_g} = -g_m \frac{r_p + \mu R}{r_p + R_L}. \tag{82}$$

A practical example of this output circuit is given in Fig. 11·42. Both tubes are pentodes, but the upper tube behaves like a triode because its plate and screen both are fixed.

A comparison of this circuit with the differential amplifier shows that for tubes of the same capabilities, the former has at least four times the gain and twice the maximum output current in both directions as the latter. On the other hand, this circuit requires a low-impedance intermediate voltage source, and, for a given available $B+$ voltage, the input voltage level must be considerably lower than that for a differential amplifier.

**11·12. Cancellation of Effect of Heater-voltage Variation.**—The fundamental effect of heater-voltage variation was explained in Sec. 11·6: A definite change of heater voltage is the equivalent of a definite change of the cathode potential relative to the other electrode potentials. For oxide-coated cathodes, a 10 per cent increase of heater voltage is the same as a cathode-potential decrease of about 100 mv, although this