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LINE AMPLIFIER FOR TELEPHONY PURPOSES

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Fig. 1.

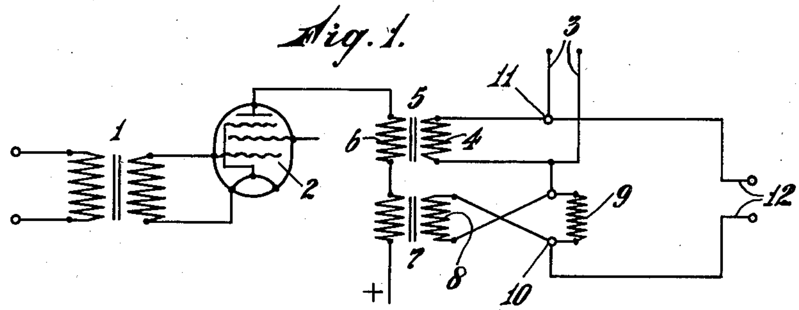


Fig. 2.

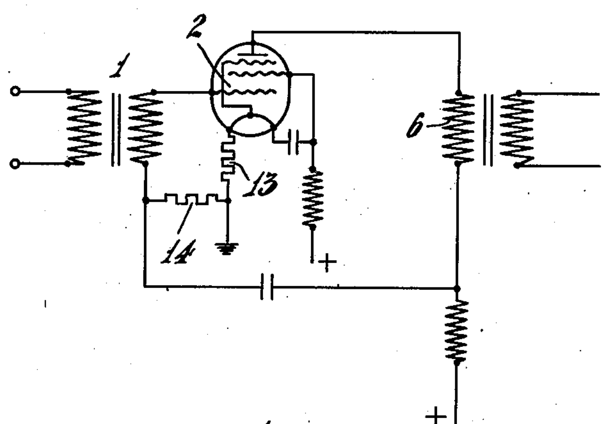
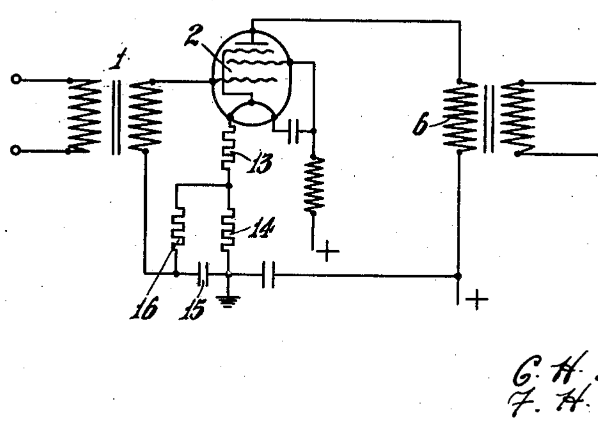


Fig. 3.



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LINE AMPLIFIER FOR TELEPHONY PURPOSES

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1 Claim. (Cl. 179—170)

The invention relates to communication line amplifiers of the kind which are inserted in long distance lines to reduce the attenuation.

In general, it is the object of this invention to provide an amplifier of this type, which shall be particularly efficient and is, at the same time, moderate in cost and economical of power.

One particular object of the invention is to provide an amplifier output stage operating into such a load as a communication line, which shall have a higher amplification than a corresponding output stage of known type, which uses a triode, and shall at the same time have an available power output at least as great as the corresponding stage using a triode.

Another specific object is to provide an output stage, such as above, in which the power required for heating the cathode and supplying potential to the anode and screen, is equal to or less than in the corresponding known type of output stage using a triode.

According to this invention, the above and other objects are attained by the use of a pentode whose degree of screening is above a certain value, connected so as to work into a load whose impedance bears at least a four to one ratio to certain characteristics of the tube.

In the accompanying drawing, several embodiments of the invention are illustrated.

Fig. 1 represents schematically an amplifier according to our invention applied to a system in which it is especially advantageous. In this system the amplifier is connected in the junction between a two-wire line and a four-wire line.

Figs. 2 and 3 represent further special applications wherein single stage amplifiers constructed according to the principles of our invention are provided with negative back coupling.

In order to more precisely define the above special relationships which are an essential feature of the invention, it is necessary to refer to a number of partial derivatives which define the characteristics of a pentode. Also, for analyzing the performance of an amplifier output stage in accordance with our invention, and for comparing it with the performance of a corresponding known output stage using a triode, certain other partial derivatives are useful. To avoid complex expressions, all these partial derivatives will be denoted, hereinafter, by convenient designations as follows:

s = partial derivative of anode current with respect to control grid potential—all other electrode potentials being constant. With respect to the usual "anode current-grid voltage" curve, s is the slope of the curve. This derivative s is well known as the "mutual conductance" of the tube.

s' = second partial derivative of anode current with respect to control grid potential—all other electrode potentials being constant. With respect to the usual "anode current-grid voltage" curve, s' is the curvature of the curve.

g = partial derivative of anode potential with respect to control grid potential—all other electrode potentials as well as the anode current being constant. This derivative g is well known as the "amplification factor" of the tube.

R_i = partial derivative of anode potential with respect to anode current—all other electrode potentials being constant. This derivative R_i is generally known as the "A. C. resistance" or "internal resistance' of the tube.

K_g = partial derivative of control grid potential with respect to total emission current—all other electrode potentials being constant.

K_a = partial derivative of anode potential with respect to total emission current—all other electrode potentials being constant.

K_{sg} = partial derivative of screen grid potential with respect to total emission current—all other electrode potentials being constant.

The amplifier according to the invention is characterized in this, that for the power-valve a pentode is used, wherein in the operating region the ratio of the small variation of the total emission current which results from a given small variation in the screen-grid voltage (other voltages being constant) to the small variation of the total emission current which results from the small variation in the anode voltage (other voltages again being constant) is of the order of 50 or higher.

$$\frac{K_a}{K_{sg}} \geq 50 \quad (1)$$

and whereby, (at least at those frequencies at which the greatest sound energies occur) the load impedance is at least equal to four times the resistance represented by K_{sg}.

$$Ru \geq 4Ksg \quad (2)$$

The ratio

$$\frac{K_a}{K_{sg}}$$

measures the extent to which the screen grid shields the anode. For convenience therefore this ratio may be called the "screening ratio." The detailed structural designs which may be used to produce a screening ratio of more than 50 are well known. In fact pentodes whose screening ratio is far above 50 have already been known, although these tubes were not used as power pentodes but rather for radio frequency amplification where freedom from feedback is the primary requirement.

It is assumed that the maximum available alternating current power is determined by the maximum allowable percentage of harmonics. Moreover with line amplifiers this percentage is lower than with other applications, since in general in an amplified line more than one amplifier occurs and all said amplifiers deliver the same power.

The maximum alternating current power of the triodes ordinarily employed in line amplifiers is not determined by a sudden limit (e. g., by the attainment of a zero value of anode voltage or anode current) but rather the limit is reached before this point. This is due to the fact that the characteristics are curved. The most important harmonic possesses a frequency which is twice the fundamental frequency and is herein called the second harmonic.

To a close degree of approximation the percentage of the second harmonics may be represented by

$$h = 100p\sqrt{\frac{W}{R_u}} \cdot \frac{R_i}{R_i + R_u} \quad (3)$$

In this equation h is the percentage, W the delivered alternating current power, R_i the internal tube resistance as previously defined, R_u the exterior resistance seen from the anode, and p is given by the equation:

$$p = .3535\frac{s'}{s^2} \quad (4)$$

The amplification A, defined as the ratio of the voltage across the normal telephone impedance (obtained on the secondary of an ideal output transformer transforming the said secondary into R_u at the primary) to the grid voltage is given by the equation:

$$A = g\frac{\sqrt{R_u.600}}{R_i + R_u} = s\sqrt{R_u.600} \cdot \frac{R_i}{R_i + R_u} \quad (5)$$

in which g is the amplification factor and s the mutual conductance of the triode as previously defined.

As far as the percentage of harmonics is concerned the following is observed:

The factor

$$\sqrt{\frac{W}{R_u}}$$

indicates the influence of the smaller current variation which in case of a higher resistance is necessary for obtaining the same alternating current power, the factor

$$\frac{R_i}{R_i + R_u}$$

indicates a kind of anode reaction.

As far as the output power is concerned, however, it is seen that the amplification becomes maximum at $R_u = R_i$. Therefore this is the normal relation for line amplifier triodes.

It can be seen from Equation 3 that by increasing R_u beyond the above mentioned value (R_i) the harmonics are reduced in a two-fold way. Since, however, the amplification decreases when R_u increases beyond R_i the above is not applied.

Now let us consider a somewhat idealized pentode having the following properties: cathode and control grid have the same structure as in a triode used for line amplifiers; the screen grid is arranged in the place of the anode of the triode (that is to say: $g_{s'}$ pentode $= g$ triode). The idealization of the pentode consists in this, that it is assumed that the entire emission current goes to the anode and that there is no anode-reaction whatever. Then with the same voltages (and heating current power) the same currents and consequently the same (curved) $I_a.V_g$— characteristics are obtained.

The percentage of harmonics =

$$100p\sqrt{\frac{W}{R_u}}$$

The amplification =

$$s\sqrt{R_u.600}$$

The following is the result of comparing these factors:

	Triode	Corresponding idealized pentode
Percentage of harmonics	$100p\sqrt{\frac{W}{R_u}} \cdot \frac{R_i}{R_i+R_u}$	$100p\sqrt{\frac{W}{R_u}}$
Amplification	$s\sqrt{R_u.600} \cdot \frac{R_i}{R_i+R_u}$	$s\sqrt{R_u.600}$

If both of these tubes are operated into loads whose impedance equals R_i of the triode, then the pentode produces twice the percentage of harmonics with the same alternating current power and also gives twice the amplification of the triode.

In order to obtain an equally small percentage of harmonics the pentode should be loaded by four times the R_i of the triode. Then the amplification becomes four times (viz. twice two times) as high as with the triode loaded by its own interior resistance.

An actual pentode, however, is not like the above assumed idealized pentode for:

1. The anode voltage does influence the total emission current.
2. The emission current is divided between the anode and the screen grid.
3. An anode voltage variation more strongly influences the division between anode and screen grid than the total emission current.

Considering only the first of the above mentioned practical limitations, if it is desired to realize the possible higher amplification of the pentode when the pentode is operating into a load which is at least four times R_i of the triode, it is necessary that

$$\frac{1}{K_a} << \frac{1}{4}\frac{1}{K_{sg}}$$

This has been done by making:

$$\frac{K_a}{K_{sg}} \geq 50$$

Considering now, the second of the above mentioned practical limitations, this reduces the effective mutual conductance s. The necessity of maintaining a small anode reaction is, therefore, even greater, in order that a high amplification may be obtained in spite of this reduction in mutual conductance.

Considering now the third of the above mentioned practical deviations from ideal, in general one can express a small change in anode current by the following equation:

$$\Delta I_a = s\Delta V_g + \frac{\Delta V_a}{R_i} + a(\Delta V_g)^2 + 2b(\Delta V_g \Delta V_a) + c(\Delta V_a)^2 + \text{ etc.}$$

in which V_a and V_g represent the anode voltage and the grid voltage, respectively.

With a triode very approximately

$$sR_i = g \text{ and also } \frac{a}{b} = \frac{b}{c} = g$$

With a pentode such is not the case because the total emission current is divided between the anode and the screen grid, and because the said division depends on the value of the voltage

$$sR_i \neq \frac{K_a}{K_g}$$

and also

$$\frac{a}{b} \neq sR_i$$

and

$$\frac{b}{c} \neq sR_i$$

A consequence of all these relationships in a pentode is that by a right choice of the proportion

$$\frac{\Delta V_a}{\Delta V_g}$$

(which amounts to a correct choice of the loading impedance) it may be arranged that of the linear factors the $s\Delta V_g$ predominates by far, whereas the square factors balance one another, at least if

$$\frac{K_a}{K_{sg}} \geq 50$$

It appears that this result occurs in case of a normal construction with a loading resistance higher than four times the R_i of the corresponding triode.

When considering the triode it has been said that points of discontinuity did not constitute the essential limitation to output volume. With the pentode the circumstances are otherwise so that here the discontinuities may constitute an effective limitation. Now it should be noted that with a triode

$$\frac{V_{ao}}{I_{ao}} > R_i$$

because a certain negative grid bias is necessary in which V_{ao} represents the normal anode voltage and I_{ao} represents the normal anode current. The result of this is that if the load impedance is equal to the interior resistance the alternating current amplitude is a larger fraction of the normal anode-current than the alternating voltage amplitude is of the normal anode voltage. In other words, if the alternating signal input were increased the limit of zero anode current would be encountered prior to the limit of zero anode voltage.

Consequently there is a suitable margin for increasing the loading resistance without reducing the amount of power which can be handled before encountering a discontinuity; the same is true of the corresponding pentode. This margin is still further increased in proportion as the maximum allowable alternating current power with the triode is reduced relative to the total supplied direct current power.

The above applies only to pentodes. With tetrodes the additional discontinuity at $V_a = V_{sg}$ imposes an additional limit on power and for this reason only pentodes are considered.

From the above analysis it appears that if the conditions according to the invention are met, a line amplifier is obtained having a higher amplification as well as a smaller percentage of harmonics for an equal delivered alternating current power, in comparison with the corresponding triode. It is thus evident that so far as the output energy is concerned, pentodes connected in accordance with our invention are definitely superior to well matched triodes, provided that the load impedance is practically constant, and furthermore it can be seen that a higher amplification may be obtained, which represents a considerable advantage for line amplifiers.

The higher amplification which is obtainable according to our invention provides an opportunity of decreasing the transformation proportion of the input transformer so that a larger width of the band and a better quality are obtained, because it is not necessary to make such high demands upon the said transformer since the amplification obtained with the pentode is very high.

If $R_i >> R_u$ a simple arrangement may be made for the change from four-wire- into two-wire-connections, whereby the acting losses are compensated by a higher amplification in the direction 4-wire to 2-wire. It is true that then the maximum delivered power will decrease but in general the maximum output energy is not required in points in which one does not pass again into a four-wire connection.

In Fig. 1 of the drawing such an arrangement is illustrated.

In such an arrangement the incoming four-wire circuit is coupled over the input transformer **1** to the grid circuit of the pentode **2**, whereas the output two-wire circuit **3** is connected with the secondary winding **4** of an output-transformer **5**, the primary winding **6** of which lies in the anode circuit of the pentode **2**.

The winding of a second transformer **7**, the secondary **8** of which is connected to the balance impedance **9**, is in series with the said winding. The two-wire conductor **3** and the balance **9** are connected in series in such a manner that their free terminals **10**, **11** produce a difference in voltage equal to zero if the line-impedance and the balance-impedance are equal. The incoming four-wire branch **12** is connected to these points.

Both transformers are of the type usual for ordinary one-way amplifiers. With a very large R_i in comparison with R_u the amplification between the grid circuit and the two wire circuit will be the same, independent of whether the second transformer is or is not present. In this connection it should be noted that the condition above specified for the load R_u (namely that it must be at least four times K_{sg}) does not in any way prevent the load from being small in comparison with R_i. The effect of the currents set up by the two-wire line through the valve impedance is so very small that it may be neglected; so that for speech transmitted from the two-wire line to the four-wire line the effect is practically the same as if terminals 3 were simply connected to terminals 12 in series with balancing resistance 9. In this case R_u is equal to twice the optimum output value (since the transformers 5 and 7 are the same type used for simple line amplifiers) so that the energy to be delivered does not reach fully the optimum value. Further in case of $R_i >> R_u$ the load impedance may be artificially increased in any frequency ranges which do not require the full maximum power output, thus permitting the attainment at certain frequencies of an amplification somewhat higher than the normal amplification. By this arrangement the unequal attenuations of the line may be compensated.

A further advantage is that the invention by providing an unusually high amplification offers an opportunity of reducing the high amplification by the use of negative back-coupling, while still having as much amplification as would be given by an ordinary triode.

Consequently the variations in the amplification grade in question being due to voltage-variations, ageing of the valves and the like become much smaller which is important for the upkeep of lines having a plurality of amplifiers, whereas the percentage of harmonics decreases considerably. This method with an auxiliary amplifier has been proposed already, but the use of pentodes makes it possible to yield a similar effect without extra valves by very simple solutions of which Figure 2 illustrates an embodiment.

In the grid circuit of the pentode 2 a resistance 13 is inserted between cathode and earth, whereas the transformer is likewise connected to earth over a second resistance 14. The latter has been designed for coupling back the alternating current, whereas the resistance 13 substantially supplies the negative grid voltage.

Many variations of this example are possible. For example the resistance 13 could be replaced by a choke-coil with shunt resistance, whereby the resistance 14 may be abandoned.

Figure 3 shows a somewhat modified arrangement. Here the resistance 14 is arranged between the resistance 13 and earth. The high resistance 16 arranged parallel to 14 and the condenser 15 provide the right grid bias.

It is also possible to make the back-coupling dependent on the frequency in order to give the remaining amplification a desired frequency course.

If the value of R_u is taken to be 50,000 to 150,000 ohms, input- and output-transformers may be used which are mutually equal. The degree of amplification of the amplifier is in that case equal to $s \cdot R_u$ and for $s=2 \cdot 5\ mA/V$ the degree of amplification becomes of the order of 125 to 375 and consequently four to twelve times that in amplifiers having a corresponding triode.

We claim:

In a communication system a communication path which includes a two-wire line and a four-wire line, having outgoing and incoming circuits, a combined amplifier and repeater connected so as to couple the two-wire line with the four-wire line, comprising in combination a pentode including a cathode, a control grid, a screen grid, a suppressor grid and an anode, the screen grid being designed to substantially completely shield the anode, an input transformer for supplying the control grid and cathode of the pentode with voltages derived from the four-wire circuit, two output transformers having their primaries connected in series with said anode, their secondaries being connected in series and in opposition in the outgoing circuit of the four-wire system, the circuit of the two-wire system being connected to one of the secondaries, and a balance network being connected to the other secondary.

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