Oct. 17, 1933. M. VOS 1,930,732

MEANS FOR THE ELIMINATION OF DISTORTION IN TELEPHONE LINES

Filed Nov. 6, 1929

Fig. 1.

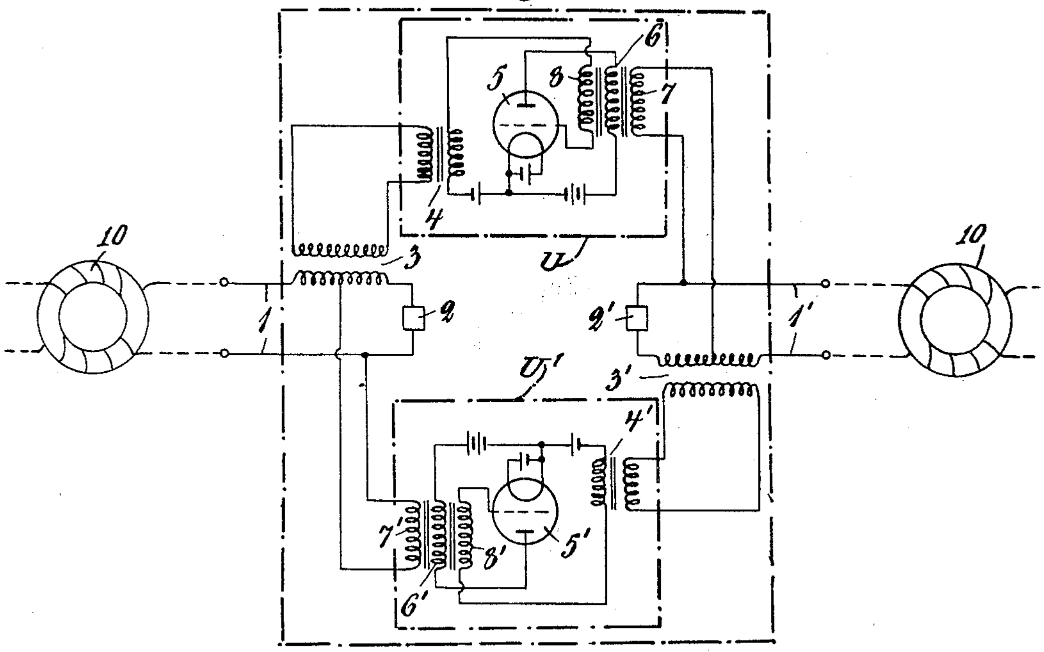
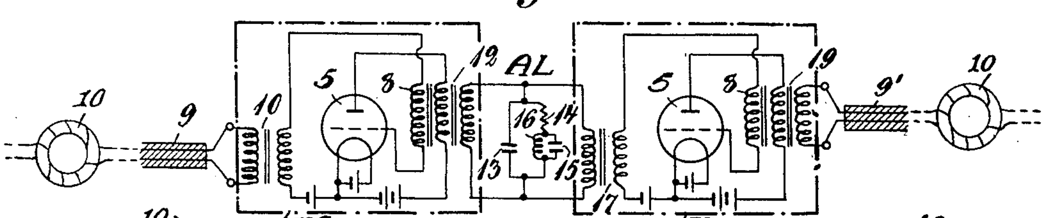


Fig. 2.



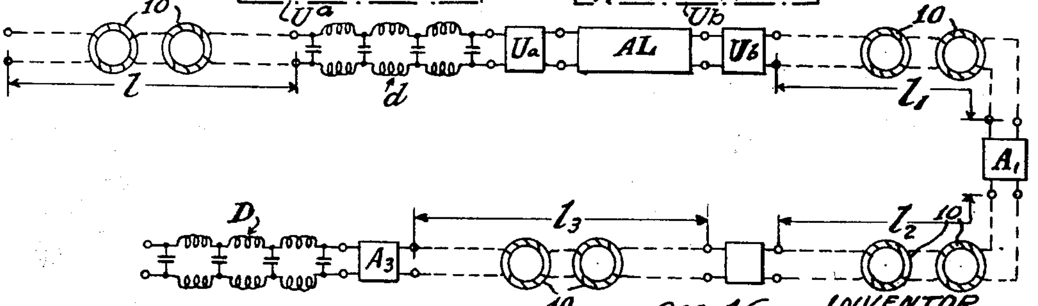


Fig. 3.

M. Vos INVENTOR.

By: Marks & Clerk

Attys.

Patented Oct. 17, 1933

1,930,732

UNITED STATES PATENT OFFICE

1,930,732

MEANS FOR THE ELIMINATION OF DISTORTION IN TELEPHONE LINES

Mauritz Vos, Stockholm, Sweden, assignor to Telefonaktiebolaget L. M. Ericsson, Stockholm, Sweden, a company of Sweden

Application November 6, 1929. Serial No. 405,217, and in Sweden November 9, 1928

10 Claims. (Cl. 178—44)

The present invention has for its object to eliminate the distortion in pupinized cables or other similar natural or artificial lines in which the characteristic impedance and damping increase with the frequency approximately according to the same function. It has been previously proposed to compensate the differences between the damping of the different frequencies by including in the line impedances or artificial lines having such properties that they exert a higher additional damping upon those frequencies which are most unaffected by the natural line damping but, on the other hand, pass those oscillations with a lower additional damping which have been most damped by the line. Said arrangement evidently weakens the speech as a whole which in turn must be compensated by amplification.

According to the invention, the problem of establishing distortionless transmission of speech currents is solved principally in a quite different manner than that used in said known arrangement, said inconvenience being then completely eliminated and besides a practically exact compensation of the distortion attained. The invention is based upon the fact that in a pupinized cable the characteristic impedance and damping vary according to the same function of the frequency. Said property of such lines is now made use of by including amplifiers as telephone repeaters in the line in which amplifiers the reaction of the anode voltage upon the grid voltage is eliminated by the retransfer of a compensating voltage from the anode circuit to the grid circuit in a manner known per se in modulators (Swedish Patent No. 62,633). An amplifier compounded in this manner operates similarly to a compounded dynamo as its anode current at a given amplitude of the supplied grid voltage will be constant and independent of the size of the output impedance. The voltage between the terminals of the output impedance will consequently be proportional to the said output impedance. If now the anode circuit is loaded by the line impedance the different frequencies will thus on account of the proportionality between the line impedance and the line damping be amplified in the same proportions in which they have previously been damped in the line. Hereby a partial elimination of the distortion is obtained which, however, as shown in the following, may be improved by a certain adjustment of the distance between the consecutive telephone repeaters on the line.

The invention will be more closely described with reference to the accompanying drawing showing different embodiments of the invention. Figure 1 is a circuit diagram of the arrangement according to one embodiment of the invention. Figure 2 shows a modified embodiment having several amplifying valves in each telephone repeater on the line. Fig. 3 shows an arrangement according to the invention in a pupinized line composed of a number of line sections.

The invention may be applied both in two-wire and four-wire amplifiers.

In Figure 1, 1 and 1′ represent two line sections united by means of a telephone amplifier each of which sections is loaded by Pupin coils 10 and in the usual manner terminates in a line balance 2 or 2′ respectively a differential repeating coil 3 and 3′ respectively being interconnected between the line and the line balance. The secondary winding of said repeating coil is connected to the input transformer 4 and 4′ respectively of a valve amplifier U and U′ respectively each comprising a three-electrode valve 5. Each of the amplifiers U and U′ together with its appertaining parts is surrounded on the drawing by a rectangle indicated by dotted lines. The output transformer of the valve is provided with three windings i. e. a primary winding 6 and 6′ respectively in ordinary manner included in the anode circuit, a secondary winding 7 or 7′ respectively connected to the outgoing line, and besides a secondary winding 8 or 8′ respectively which latter is connected into circuit between the grid and the secondary winding of the input transformer. The two-wire amplifier as a whole including the two amplifier units U and U′ and the differential repeating coils 3 and 3′ is surrounded by an outer rectangle shown by dotted lines. The winding 8 or 8′ respectively has for its purpose to retransfer a compensating voltage from the anode circuit to the grid which voltage is adapted to exactly neutralize the reaction of the anode load upon the control voltage. As regards the alternating current portion $V_R\sim$ of the grid voltage one has

$$V_R\sim = V_g\sim + \frac{V_a}{\mu} + \delta V_a\sim$$

where $V_g\sim$ is the alternating component of the grid potential and μ is the ratio of amplification. The second term on the right hand side represents the reaction of the variable anode voltage $V_a\sim$ upon the grid voltage. The third term represents the compensating voltage which is retransferred through the compensating winding 8 and 8′ respectively to the grid from the anode circuit. This compensation is so selected that

$$\frac{V_a\sim}{\mu}+\delta V_a=O$$

whereby said reaction is completely eliminated. As a consequence, the amplifier will operate according to a dynamic characteristic which completely coincides with the static characteristic. At a given amplitude of the supplied grid potential and a given frequency the anode current will thus be independent of the value of the external anode impedance and maintains at different loads the same intensity as at short-circuit. The valve will in other words operate as a compounded dynamo having constant current. The output voltage of the valve will thus at various frequencies be proportional to the absolute value of the characteristic impedance on the output side, and if now this impedance varies with the frequency in the same manner as does the damping of the line, the output voltage will obviously be proportional to the line damping at the same frequencies. Those frequencies which are most subjected to damping in the line section in front of the amplifier will thus obtain the highest amplification.

The line distortion is, however, only partially compensated by the above described arrangement alone. Whereas the output voltage of the amplifier for the different frequencies is directly proportional to βl where β is the damping coefficient of the line and l the length of the line section in question, the damping in the line section in front of the amplifier conforms, on the other hand, with the exponential function $e-\beta l$.

Experience has shown, however, that by a suitable adjustment of the distance between the amplifier stations one may bring about that the amplification at different frequencies practically compensates the damping of the preceding line section. This fact may be explained by the following short mathematic calculation:

The characteristic impedance Z of the line and the damping coefficient β vary as above mentioned according to one and the same function of the angular frequency ω and are

$$Z=\frac{Z_0}{\sqrt{1-\left(\frac{\omega}{\omega_0}\right)^2}};\quad \beta=\frac{\beta_0}{\sqrt{1-\left(\frac{\omega}{\omega_0}\right)^2}}$$

where Z_o is the characteristic at low frequencies (theoretically at $\omega=0$). In analogous manner β_o designates the line damping at low frequencies.

$$\frac{\omega_0}{2\pi}$$

is the limiting frequency of the line.

As the anode current i_a on account of the compounding of the amplifying valve is independent of the output impedance and equal to the anode current at short-circuiting the valve on the output side one may evidently put

$$i_a=\frac{\mu\cdot\mu_1\cdot V_2}{R_i}$$

where $\frac{1}{\mu}$ is the ratio of the input transformer 4, V_2 the voltage on the primary side of the input transformer, and R_i the internal resistance of the amplifying valve. μ designates as before the amplification ratio of the valve. As regards the voltage between the primary terminals of the output transformer 6, 7, 8 one may put

$$V_a=i_a\cdot Z\cdot\mu_2^2$$

where Z is the line impedance and μ_2 the ratio of transformation between the windings 7 and 8 in the output transformer. As regards the voltage V_3 between the secondary terminals of the output transformer one has thus

$$V_3=\frac{V_a}{\mu_2}=\frac{\mu\mu_1\mu_2}{R_i}\times\frac{Z_0\cdot V_2}{\sqrt{1-\left(\frac{\omega}{\omega_0}\right)^2}}=\frac{K\cdot V_2}{\sqrt{1-\left(\frac{\omega}{\omega_0}\right)^2}},\text{ where } K=\frac{Z_0}{R_i}\cdot\mu\mu_1\mu_2.$$

If it is assumed, for the sake of simplicity, that the line section l is directly connected to the primary terminals of the input transformer 4, as is the case in four-wire repeaters, one has as regards the proportion between the output voltage V_3 and the voltage V_1 at the beginning of next preceding line section

$$\frac{V_3}{V_1}=\frac{V_2}{V_1}\cdot\frac{V_3}{V_2}=e^{\left[\log_e\frac{V_3}{V_2}-\beta l\right]}=e^{(s-\beta l)}$$

where e is the basis of the hyperbolic logarithms and $s=\log_e\frac{V_3}{V_2}$ is the amplification. After development in series the expression

$$s=\log_e K+\tfrac{1}{2}\left(\frac{\omega}{\omega_0}\right)^2\left[1+\tfrac{1}{2}\left(\frac{\omega}{\omega_0}\right)^2+\tfrac{1}{3}\left(\frac{\omega}{\omega_0}\right)^4+\text{----}\right]$$

is obtained. Further

$$\beta l=\beta_0 l+\tfrac{1}{2}\beta_0 l\left(\frac{\omega}{\omega_0}\right)^2\left[1+\tfrac{3}{4}\left(\frac{\omega}{\omega_0}\right)^2+\frac{3.5}{4.6}\left(\frac{\omega}{\omega_0}\right)^4+\text{----}\right]$$

thus

$$s-\beta l=\log_e K-\beta_0 l+\tfrac{1}{2}\left(\frac{\omega}{\omega_0}\right)^2\left\{\left[1+\tfrac{1}{2}\left(\frac{\omega}{\omega_0}\right)^2+\tfrac{1}{3}\left(\frac{\omega}{\omega_0}\right)^4+\text{----}\right]-\beta_0 l\left[1+\tfrac{3}{4}\left(\frac{\omega}{\omega_0}\right)^2+\text{----}\right]\right\}$$

In order to bring $(S-\beta l)$ approximately to zero one has evidently

$$\log_e K-\beta_0 l=0;\quad \beta_0 l=1$$

i. e.

$$\log_e K=1 \text{ or } K=e, \text{ thus } \frac{Z_o}{R_i}\mu\mu_1\mu_2=e$$

in which case

$$s-\beta l=\tfrac{1}{2}\left(\frac{\omega}{\omega_o}\right)^2\left[-\tfrac{1}{4}\left(\frac{\omega}{\omega_o}\right)^2-\tfrac{7}{24}\left(\frac{\omega}{\omega_o}\right)^4\right]$$

which expression is infinitely small at frequencies which are not too close to the limiting frequency

$$\frac{\omega_o}{2\pi}.$$

It is thus understood that a practically complete elimination is obtained if the distance between consecutive amplifier stations is so selected that the line damping at low frequencies reaches nearly one Neper. Said distance may be designated by L_m.

One is, however, as will be shown in the following, not limited to such a fixed distance between the amplifier stations.

Figure 2 shows an arrangement in connection with a four-wire amplifier by means of which arrangement one may be independent of such a fixed station distance. The numerals

9 and 9′ represent the ends of the line for instance a pupinized cable, in which is inserted a repeater for the one transmission direction comprising two valves U_a and U_b each of which together with its appertaining parts is surrounded in Figure 2 by a rectangle indicated by dotted lines. The incoming line 9 is connected to the input side of a valve U_a arranged in the same manner as the valve U in Fig. 1 and the output side of said valve U_a is connected to an artificial line AL the characteristic impedance of which varies with the frequency substantially in the same manner as does the damping of the line 9 but which, on the other hand, is practically free from damping. The artificial line in question consists of two mutually parallel connected impedances the one of which consists of a condenser 13 and the other of a resistance 14 in series with an inductance 16 connected in parallel with the condenser 15. The other end of the artificial line is connected to the input side of the second valve U_b which is equal to U_a and the output side of which is connected to the outgoing line section 9′. Each of the two output transformers 12 and 19 are in conformity with the output transformer 6, 7, 8 in Figure 1 provided with a compensating winding 8 to retransfer compensating potential to the grid in above described manner.

The circuit arrangement according to Figure 2 represents thus a combination of two amplifier units separated by a line section free of damping. As the artificial line AL has the same characteristic as the natural line the incoming oscillations is in the first valve U_a subjected to an amplification which, as regards all of the incoming frequencies, nearly compensates the damping for a line distance of the length L_m. The oscillations thus amplified continue without being damped through the artificial line AL to the second amplifier U_b in which they are subjected to a new amplification sufficient to compensate for a further line distance L_m. The line section in front of the amplifier station may thus in this case be of the double length $2L_m$ in comparison with that in the arrangement having only one amplifying valve.

In similar manner the amplifier station may be composed by three or more amplifying units in sequence and mutually separated by artificial lines constituting reproductions free of damping of a line section of the length L_m. Distortionless transmission may thus be established in line sections of the length L_m, $2L_m$, $3L_m$ etc.

The arrangement may, however, be completely independent of the calculated unit length L_m and the distance between the amplifier stations may then be selected solely in regard to the geographic conditions. This is rendered possible simply thereby that the number of amplifier valves connected in sequence in the amplifier station is chosen in such a manner that the amplifier station by itself compensates the damping of the number of whole unit lengths L_m which just exceeds the length of the next line distance, besides which an artificial damping corresponding to the excess of amplification then obtained is connected into circuit in sequence to the amplifier units in the amplifier station.

In long lines having a plurality of amplifier stations it has only to be observed that the total number of valves included in the line for the one speech direction and distributed on the different amplifier stations compensate the damping for the number of whole unit lengths L_m which just exceeds the total length of the line distance besides which an artificial damping is connected into the line corresponding to the excess of amplification thus obtained.

Arrangements of the kinds just mentioned are illustrated in Figure 3. Between the end of a loaded line or line sectional of length 1 and the appertaining amplifier is inserted an artificial line d consisting of series inductances and shunt capacities and having the same characteristic impedance as the line and a damping which is smaller than l Neper and so chosen that the sum of the dampings of the line and the artificial line d corresponds to a number of whole unit lengths L_m. It may be assumed for instance that the length l of the line is equal to 1, 8 unit length and that accordingly the damping of the artificial line d is 0,2 Neper. The valve amplifier may be of the kind described in Fig. 2 comprising two unit valves U_a and U_b separated from one another by an artificial line AL having the same characteristic impedance as the line.

To the line l is connected another line composed of three sections of the lengths l_1, l_2, l_3 respectively, to the ends of which line sections are connected amplifiers A_1, A_2, A_3 of the kinds previously described. To the end of this line is connected an artificial line D equivalent to a length of line smaller than L_m and so chosen that the sum of said equivalent length and the length $l_1+l_2+l_3$ of the line is equal to a number of whole unit lengths L_m. Assuming for instance that $l_1=0{,}9\ L_m$, $l_2=1{,}2\ L_m$ and $l_3=1{,}8\ L_m$ the damping of the artificial line D should be 0,1 L_m and the amplifiers A_1, A_2, A_3 should be so arranged as to compensate together a damping corresponding to 4 L_m.

I claim:—

1. An arrangement for eliminating distortion in a transmission line comprising in combination, a valve amplifier, means compensating substantially the reaction of the anode voltage of the valve amplifier upon its grid voltage, and means causing the output impedance of the valve amplifier to vary with the frequency substantially in the same manner as does the damping of the transmission line.

2. An arrangement for eliminating distortion in a loaded transmission line, the characteristic impedance and damping of which vary substantially according to the same function of the frequency, comprising in combination a valve amplifier inserted between consecutive sections of said line, and means compensating substantially the reaction of the anode voltage of the valve amplifier upon its grid voltage.

3. An arrangement for eliminating distortion in a loaded transmission line comprising in combination a valve amplifier inserted between consecutive sections of said line, means compensating substantially the reaction of the anode voltage of the valve amplifier upon its grid voltage, and means causing the characteristic impedance on the output side and the damping of the line to vary substantially according to the same function of the frequency.

4. An arrangement for eliminating distortion in a transmission line, comprising in combination, a valve amplifier, a feed back connection for retransferring a compensating voltage from the anode circuit to the grid circuit of the valve amplifier so as to eliminate substantially the reaction of the anode voltage upon the grid voltage, and means causing the output impedance of the valve amplifier to vary with the frequency sub-

stantially in the same manner as does the damping of the transmission line.

5. An arrangement for eliminating distortion in a transmission line, comprising in combination, a valve amplifier, a feed back connection adapted to retransfer, independently of the frequency, a constant fraction of the anode potential substantially eliminating the reaction of the anode voltage upon the grid voltage, and means causing the output impedance of the valve amplifier to vary with the frequency substantially in the same manner as does the damping of the transmission line.

6. An arrangement as claimed in claim 1, characterized in that the internal resistance R_i of the amplifier valve and the amlification factor μ of the valve and the ratios of transformation $\frac{1}{\mu_1}$ and μ_2 of the input and output transformer respectively, counted in the direction of the propagation of the oscillations, are so selected in relation to the line characteristic Z_o at low frequencies that

$$\frac{Z_o}{R_i}\mu\mu_1\mu_2 = e$$

where e is the basis of the hyperbolic logarithms the total amplification of the repeater at low frequencies then substantially compensating the damping of the same frequencies in the next preceding line section.

7. An arrangement according to claim 1, characterized in that the amplifier is adapted to compensate the damping of a preceding line section having a damping of 1 Neper.

8. An arrangement for eliminating distortion of a transmission line, comprising in combination an amplifier composed of a number of valves, means for compensating substantially the reaction of the anode voltage upon the grid voltage in each of said valves, an artificial line inserted between each two consecutive amplifiers said artificial line being nearly free of damping and having a characteristic impedance varying with the frequency substantially in the same manner as thus the damping of the line, and means causing the output impedance of the amplifier to vary with the frequency substantially in the same manner as does the damping of the line.

9. An arrangement as claimed in claim 1, characterized in that the number of amplifier valves connected in sequence to the repeater is so selected that the repeater by itself compensates the damping for the number of whole unit lengths having the damping one Neper which just exceeds the length of the next line section besides which an articficial line is included in sequence to the natural line and having the same characteristic as the latter line and corresponding to the excess of amplification in the repeater.

10. An arrangement as claimed in claim 1, characterized in that the total number of amplifiers included in the talking channel together compensate the damping for that number of whole unit lengths each having the damping one Neper which just exceeds the total line length besides which in sequence to the line an artificial line is connected into circuit with the same characteristic as the former line and corresponding to the excess of the total amplification of all the amplifiers connected into circuit.

MAURITZ VOS.