June 24, 1930. A. C. BARTLETT 1,767,200

LINE BALANCE FOR LOADED TELEPHONE CIRCUITS

Original Filed March 30, 1925

FIG. 1

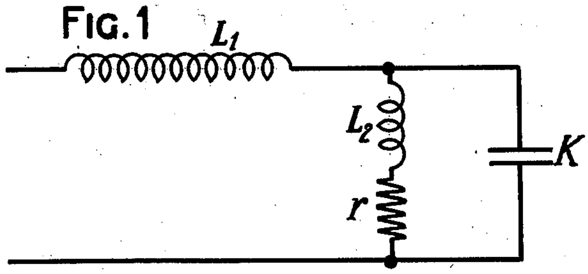


FIG. 2

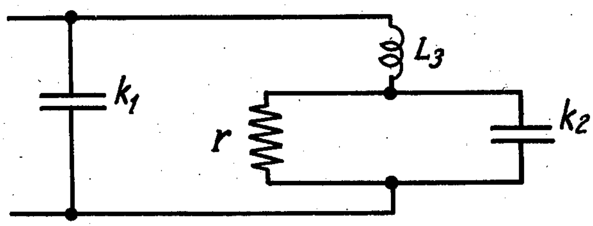
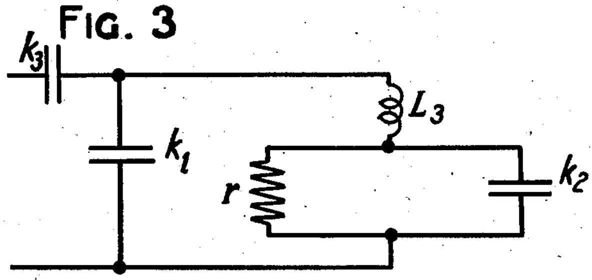


FIG. 3



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UNITED STATES PATENT OFFICE

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LINE BALANCE FOR LOADED TELEPHONE CIRCUITS

Original application filed March 30, 1925, Serial No. 19,421, and in Great Britain April 4, 1924. Divided and this application filed March 25, 1927. Serial No. 178,458.

This invention relates to line balances for loaded telephone circuits. The problem of making satisfactory line balances is that of devising some comparatively simple and cheap combination of impedance elements which shall have at all telephonic frequencies an impedance nearly the same as the sending end impedance of the actual line.

The object of the invention is to provide improved line balances the impedance of which can be made to simulate closely over the range of telephonic frequencies the impedance of a periodically loaded cable which is terminated at half cable section or over a considerable range of fractional cable section terminations. By a cable section is meant the length of cable between two loading coils.

In the accompanying drawing, Fig. 1 shows one form of the invention, and Figs. 2 and 3 show modifications.

A line balance according to the present invention consists of a new arrangement of elements having inductance, capacity and resistance, the values of which may be determined in terms of the constants of the line to be balanced, as hereinafter more fully described. Although the line balance described in this specification is primarily a mid-cable section balance, yet it can be adapted to balance the line over a considerable range of fractional cable section terminations.

It has been shown in patent application Serial No. 19,421, filed March 30, 1925, and of which this is a divisional application, that the network shown in Fig. 1 may be arranged so that over the useful telephonic range the net work gives a non-reactive resistance decreasing with frequency in a desired manner, for let us consider the impedance of a periodically loaded cable, and let

Z=Impedance of an infinite periodically loaded line starting from the middle point of a loading coil.
n=Frequency of the current in the line.
H=Inductance of each of the loading coils.
l=Distance between loading coils.
C=Capacity per unit length of line.
L=Inductance per unit length of line.
R=Resistance per unit length of line.
$p=2\pi n$.
$j=\sqrt{-1}$.

Then if the inductance of the line apart from the loading coils be negligible it is known that

$$Z=\sqrt{\frac{H}{Cl}-\frac{H^2p^2}{4}-\frac{jR}{pC}} \quad (1)$$

In practice both $\frac{H^2p^2}{4}$ and $\frac{R}{pC}$ are always less than $\frac{H}{Cl}$.

$$\text{Hence } Z=\sqrt{\frac{H}{Cl}-\frac{H^2p^2}{4}}-\frac{1}{2}\cdot\frac{jR}{pC}\cdot\frac{1}{\sqrt{\frac{H}{Cl}}} \quad (2)$$

The imaginary term on the right of equation (2) represents a condenser of capacity

$$k=\frac{2C}{R}\sqrt{\frac{H}{Cl}};$$

therefore one element of the line balance will be a series condenser of this capacity.

The network shown in Fig. 1, by choosing suitable values of the elements can be made such that the network has a resistance decreasing with frequency according to the relation shown in equation (2), and is of zero reactance the values of the elements being definitely related to the electrical constants of the line, and being determined in the following manner:—

The impedance of the network of Fig. 1 is given by

$$Z^1=jpL_1+\frac{1}{jpK+\frac{1}{r+jpL_2}} \quad (3)$$

$$=jpL_1+\frac{jp(L_2(1-p^2KL_2)-Kr^2)}{(1-p^2L_2K)^2+p^2K^2r^2}+\frac{r}{(1-p^2L_2K)^2+p^2K^2r^2} \quad (4)$$

The real part of Z^1, that is the resistance component of the impedance of this network, is

$$\frac{r}{1+p^2(K^2r^2-2KL_2)+p^4K^2L^2_2} \quad (5)$$

which is of the form

$$\frac{r}{1+ap^2+bp^4} \quad (6)$$

Now the resistance component of the cable impedance from Equation (2) is seen to be

$$\sqrt{\frac{H}{Cl}}\sqrt{\frac{1-p^2HCl}{4}}$$

which for simplicity can be written

$$B\sqrt{1-Ap^2} \quad (7)$$

where

$$B=\sqrt{\frac{H}{Cl}} \text{ and } A=\frac{HCl}{4}$$

By making $r=B$ and choosing K and L_2 of suitable values these expressions (6) and (7) can be made to have very nearly equal values over a large range of values of p.

Already we have $r=B$ so that the expressions are equal at zero frequency, and further we can make the two expressions have equal values at two other frequencies. These frequencies should be near the middle and near the upper limit of the band of speech frequencies, i. e., about 7000 and 12000 radians per second.

The procedure is first to determine the values of

$$\sqrt{1-Ap^2}$$

near the two frequencies mentioned above. For example for a medium loaded cable the values of

$$\sqrt{1-Ap^2}$$

are about 0.9 and 0.6.

The problem then is to make

$$\frac{1}{1+ap^2+bp^4}$$

and

$$\sqrt{1-Ap^2}$$

have the values .9 and .6 at the same frequencies. For the frequency at which

$$\sqrt{1-Ap^2}$$

has the value .9

$$1-Ap^2=.81$$
$$Ap^2=.19$$
$$p^2=\frac{.19}{A}$$

Thus we must have

$$\frac{1}{1+\frac{.19a}{A}+b\left(\frac{0.19}{A}\right)^2}=0.9$$

$$1=0.9+\frac{.171a}{A}+\frac{0.0325b}{A^2}$$

and for the other value in a similar way

$$1=0.6+\frac{0.384a}{A}+\frac{0.246b}{A^2}.$$

Solving these equations for a and b

$$b=A^2\times1.01 \text{ and } a=A\times.396.$$

Thus

$$K^2r^2-2KL_2=.396A$$
$$K^2L^2_2=1.01A^2$$

Thus

$$KL_2=A \text{ (approximately)}$$
$$K^2r^2=2.396A.$$
$$L_2=.645B\sqrt{A}$$
$$K=\frac{1.55\sqrt{A}}{B}$$
$$r=B.$$

Thus L_2K and r are now all determined in terms of constants of the cable.

The reactance of the network of Fig. 1 is from (4)

$$L_1+\frac{p(L_2(1-p^2KL_2)-Kr^2)}{(1-p^2KL_2)^2+p^2K^2r^2}$$

Substituting values from above in the second term of this expression, the term becomes

$$\frac{-p(0.905r\sqrt{A}+0.645rA^{3/2}p^2)}{1+0.4p^2A+p^4A^2}$$

In practice this is approximately equal to

$$-0.905p.r.\sqrt{A}$$

and therefore represents a negative inductance.

Accordingly if we make

$$L_1=0.905\,r\sqrt{A}$$

the reactance of the network of Fig. 1 will be zero, and we shall have a network which over the useful telephonic range gives a non-reactive resistance decreasing with frequency in the desired manner, the value of each element being determined by constants of the cable in accordance with the following table:—

$$L_1=0.45H$$
$$L_2=0.32H$$
$$K=0.77Cl$$
$$r=\sqrt{\frac{H}{Cl}}$$

Now if the impedance of a periodically loaded cable terminated at half cable section be considered a closely approximate expression for the impedance is

$$Z=\sqrt{\frac{H}{Cl}}\cdot\sqrt{\frac{1-\frac{jRl}{pH}}{1-p^2\cdot\frac{HCl}{4}}}$$

This can be expanded into the form

$$Z=\frac{\sqrt{\frac{H}{Cl}}}{\sqrt{1-p^2\cdot\frac{HCl}{4}}}-\frac{jRl}{2pH}\cdot\frac{\sqrt{\frac{H}{Cl}}}{\sqrt{1-p^2\cdot\frac{HCl}{4}}} \quad (8)$$

The second term can be closely represented by a series condenser of value

$$2\frac{\sqrt{HCl}}{Rl}$$

while the first term represents a resistance increasing with frequency of the form

$$\frac{B}{\sqrt{(1-Ap^2)}}$$

where B and A have the same significance as above.

It has already been shown that a network of the form shown in Fig. 1 can be made to simulate the impedance

$$B\sqrt{1-Ap^2}.$$

It should be noticed that the product of

$$B\sqrt{1-Ap^2}$$

and

$$\frac{B}{\sqrt{(1-Ap^2)}}$$

is equal to B^2, which is of the dimensions (constant resistance)^2.

If, now, the network be constructed as shown in Fig. 2 such that

$$k_1=\frac{L_1}{r^2}$$

$$k_2=\frac{L_2}{r^2}$$

$$L_3=r^2K$$

it can be demonstrated easily that the product of its impedance and the impedance of the network shown in Fig. 1 is equal to r^2 which equals B^2.

Thus since this latter network closely represents the resistance $B\sqrt{1-Ap^2}$ the required network must closely represent the resistance

$$\frac{B}{\sqrt{1-Ap^2}}.$$

Inserting values of L_2, L_1, K and r previously obtained we have

$$k_1=0.45\ Cl$$
$$k_2=0.32\ Cl$$
$$L_3=0.78\ H.$$

The mid-cable balance consists of the network of Fig. 2 having the values stated, in series with a capacity k_3 of value $k_3=$

$$2\frac{\sqrt{HCl}}{Rl},$$

and the complete balance is shown in Fig. 3.

Since the short length of cable between consecutive loading coils can be represented closely by a shunt capacity Cl it follows that by changing the value k_1, the balance can be made to simulate the cable approximately for any termination between full cable and $(0.5-0.45)=.05$ cable termination, in which case $k_1=0$.

I claim:—

1. A line balance, the impedance of which over the range of telephonic frequencies simulates closely the sending end impedance of a periodically loaded cable terminated at half cable section, comprising a number of elements including one capacity arranged in parallel with a group of elements comprehending an inductance in series with a resistance and a second capacity connected in parallel with the resistance and a third capacity placed in series with the parallel circuits afforded by the one capacity and the group of elements, the values of the several elements being determined in terms of the constants of the line to be balanced, substantially as described.

2. A line balance, the impedance of which over the range of telephonic frequencies simulates closely the sending end impedance of a periodically loaded cable terminated at a fractional cable section termination comprising a number of elements including one capacity adjusted to the desired fractional cable termination, and arranged in parallel with a group of elements comprising an inductance in series with a resistance and a second capacity connected in parallel with the resistance, and a third capacity placed in series with the parallel circuits afforded by the one capacity and the group of elements, the values of the several elements of the balance first being determined in terms of the constants of the line to be balanced, substantially as described.

3. A line balance the impedance of which over the range of telephonic frequencies simulates closely the sending end impedance of a periodically loaded cable terminated at a small fractional cable section termination, comprising a number of elements including one capacity adjusted to a value corresponding with the desired fractional cable section termination said value being included within a range of values having zero as one limit thereof, the said capacity being arranged in parallel with a group of elements comprising an inductance in series with a resistance and a second capacity connected in parallel with the resistance, and a third capacity con-

nected in series with the parallel circuits afforded by the one capacity and the group of elements, the values of the several elements of the balance first being determined in terms of the constants of the line to be balanced.

In testimony whereof I affix my signature.

ALBERT CHARLES BARTLETT.