R. S. HOYT.
TWO WAY IMPEDANCE EQUALIZER FOR TRANSFORMERS.
APPLICATION FILED NOV. 29, 1918.

1,430,808.

Patented Oct. 3, 1922.

3 SHEETS—SHEET 1.

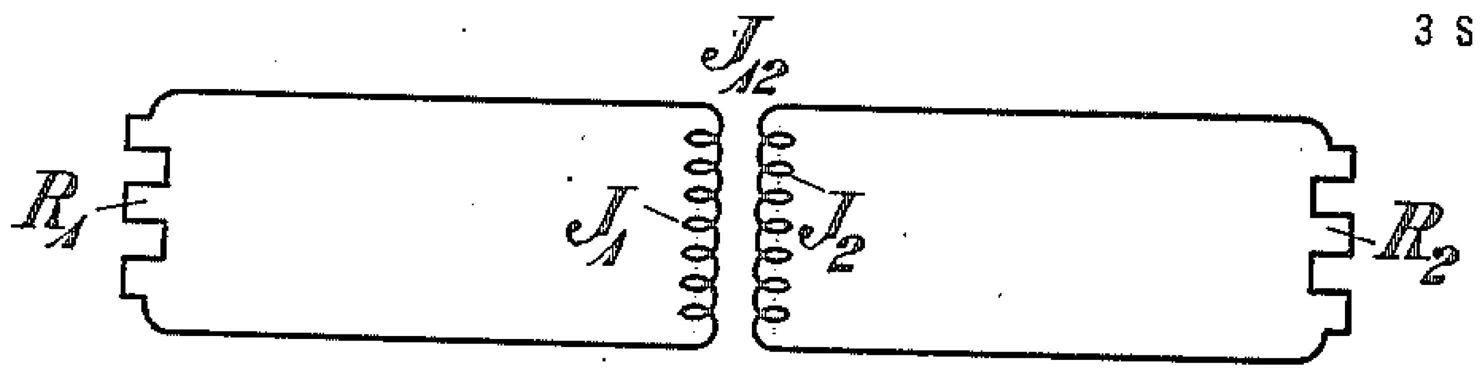

Fig. 1

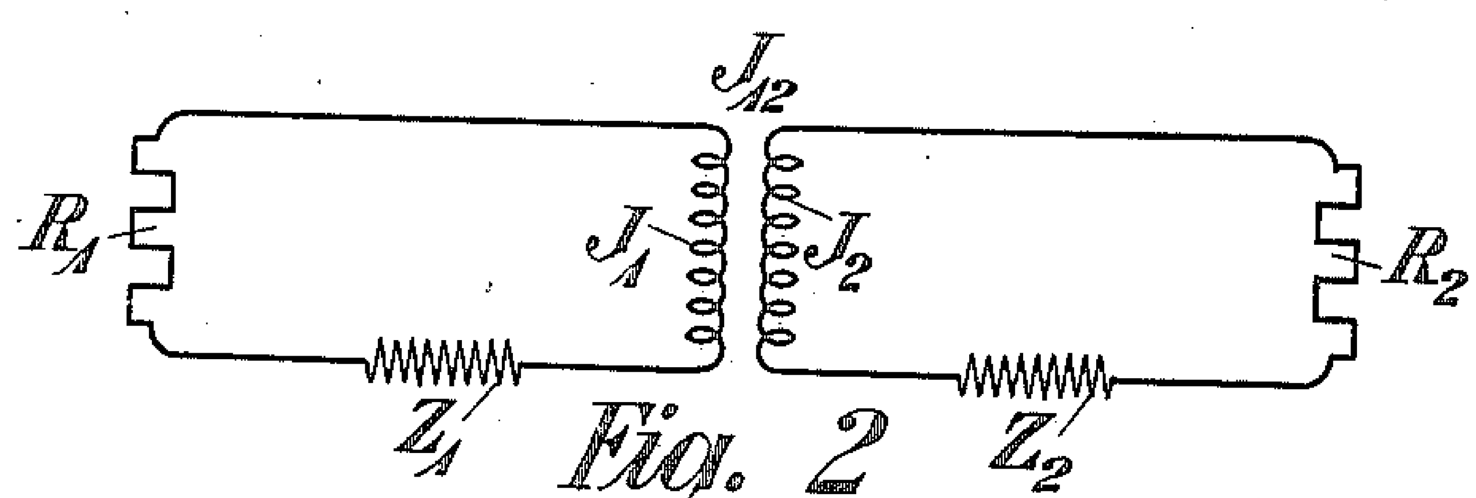

Fig. 2

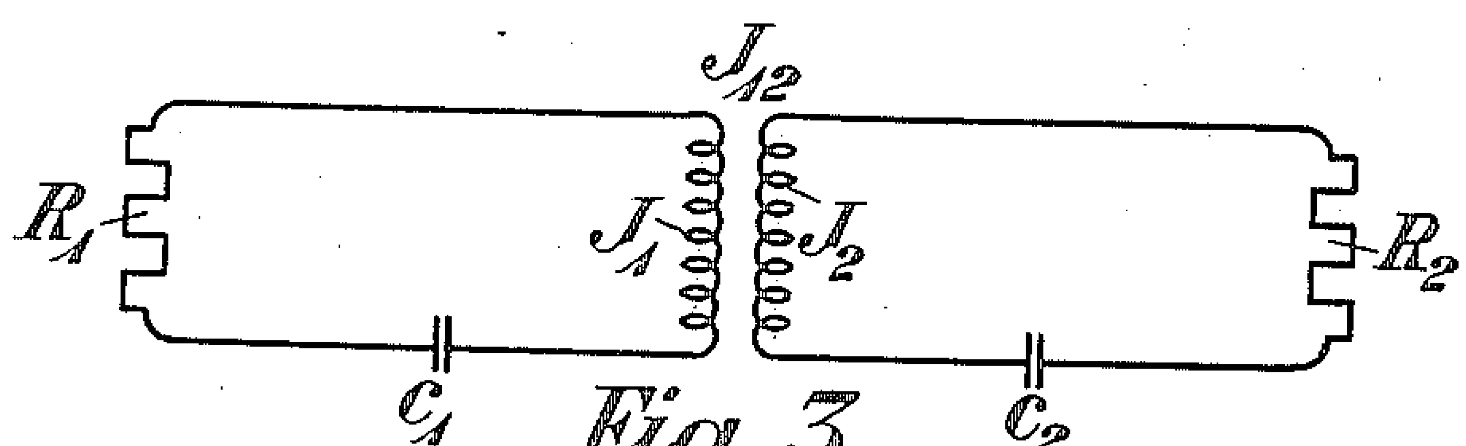

Fig. 3

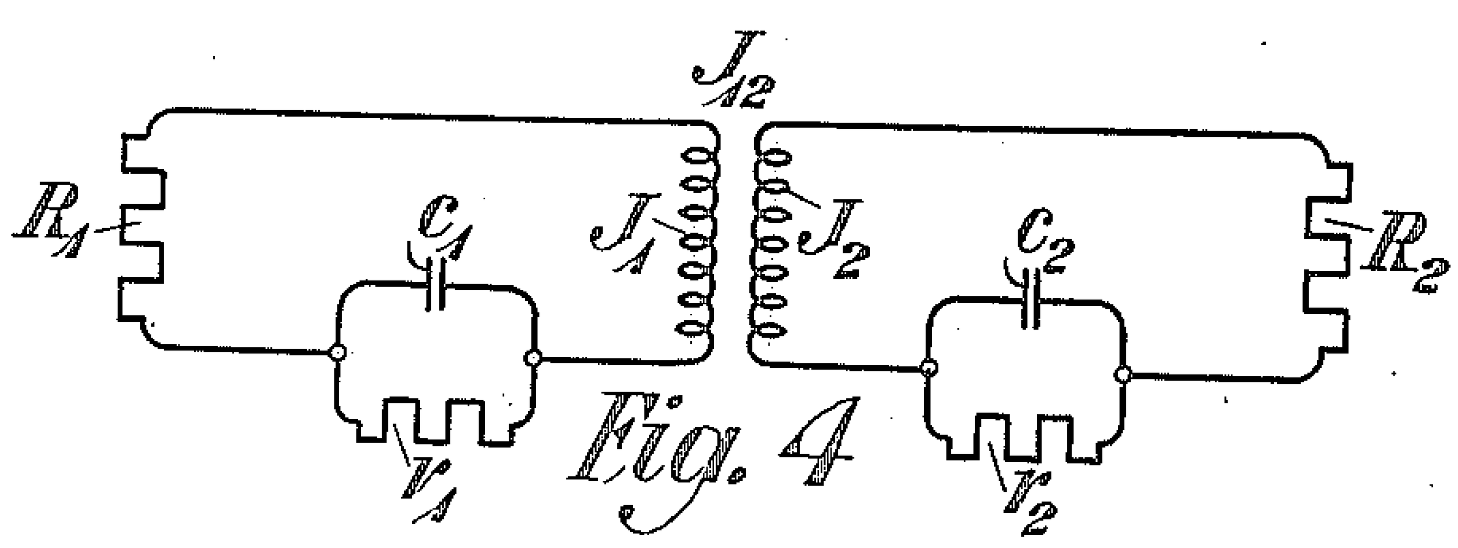

Fig. 4

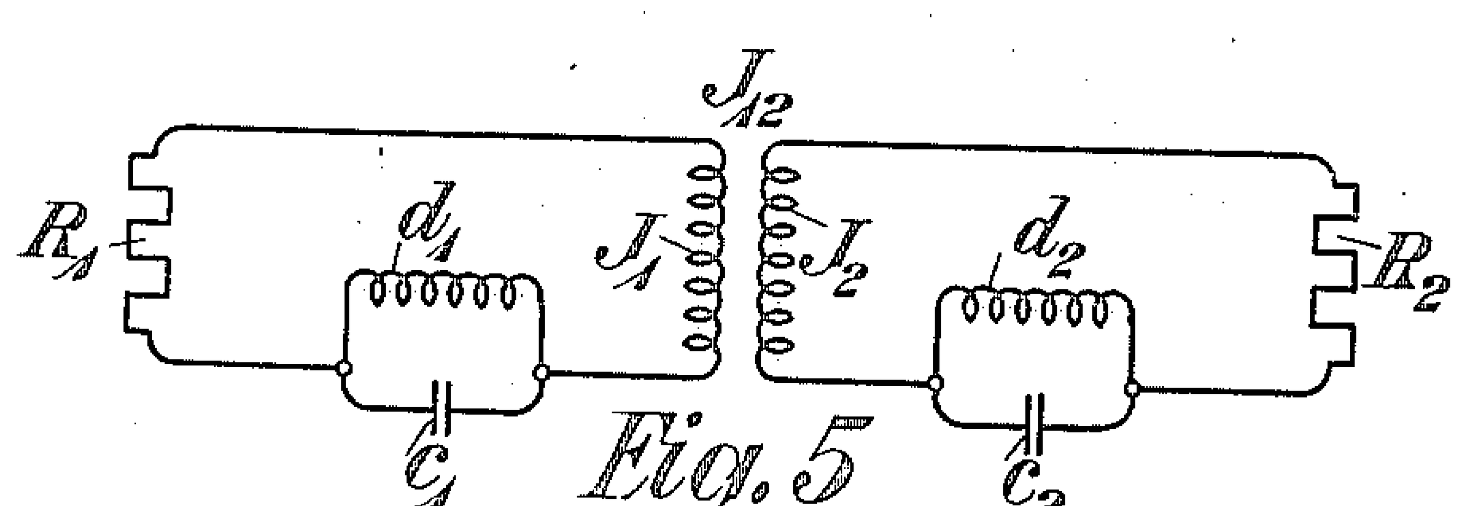

Fig. 5

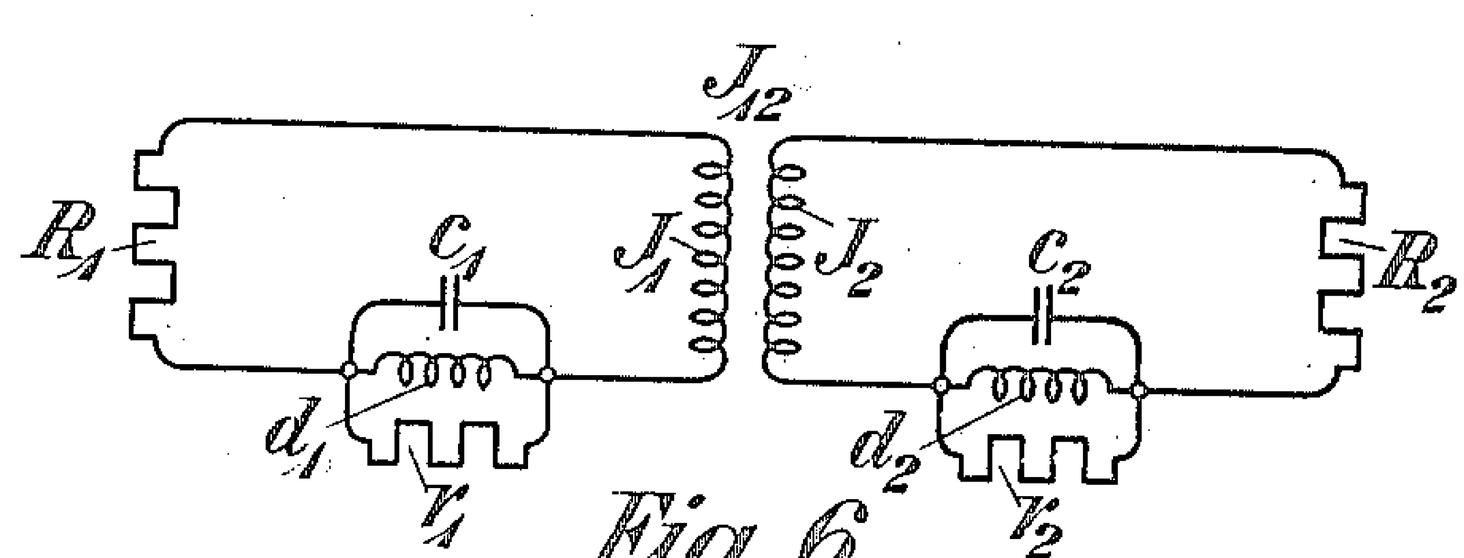

Fig. 6

INVENTOR.
R. S. Hoyt
BY G. E. Folk.
ATTORNEY

R. S. HOYT.

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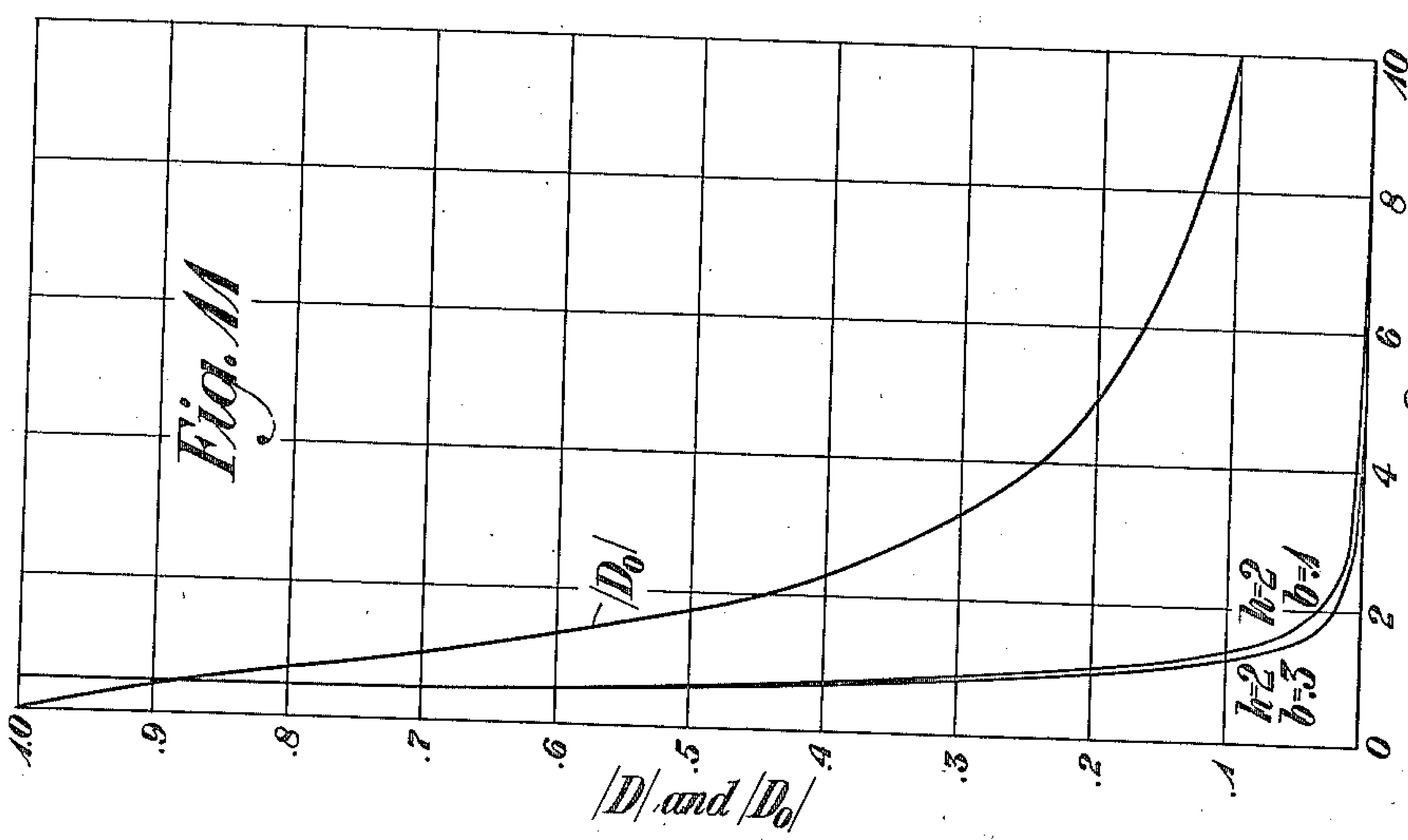

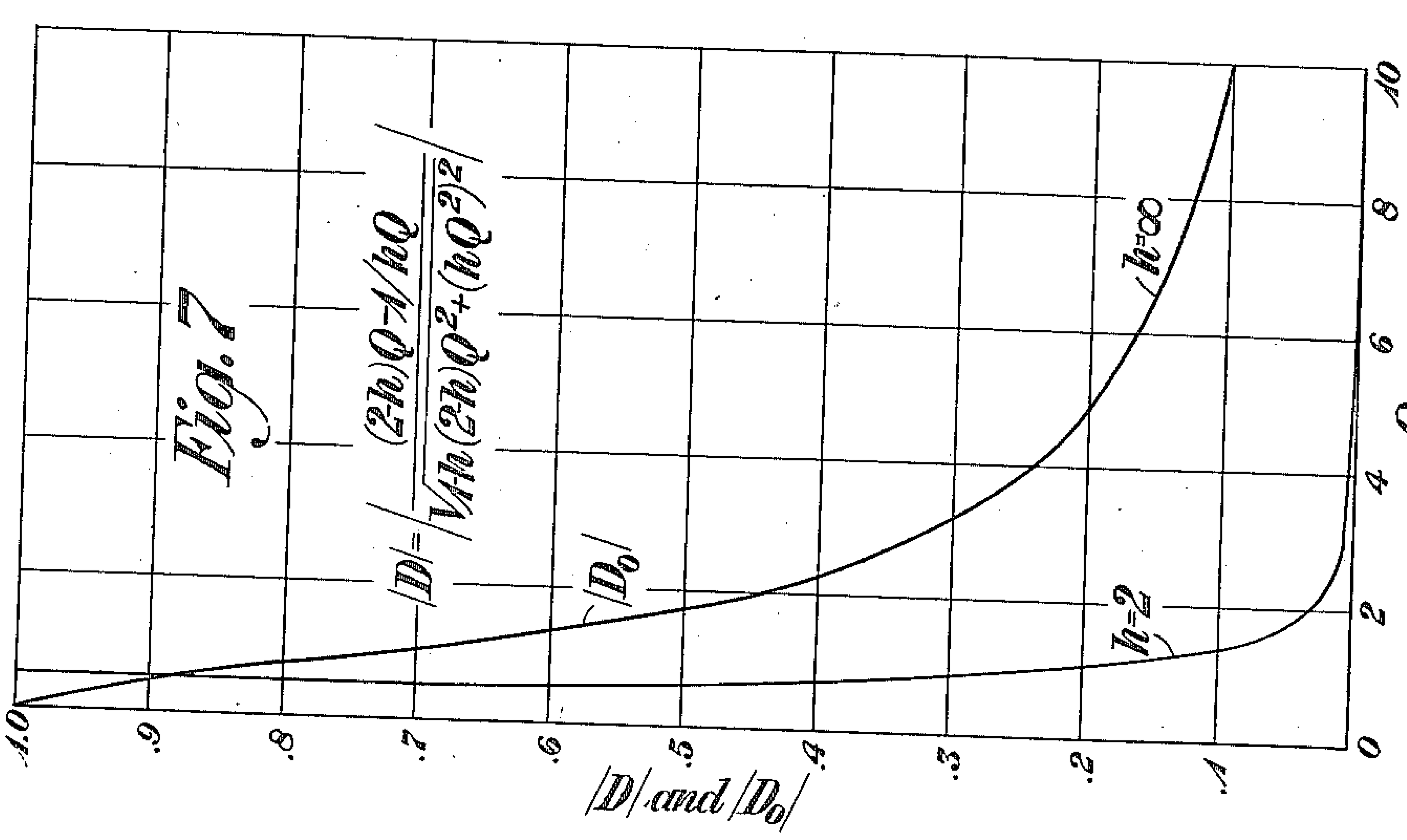

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BY G. E. Folk.

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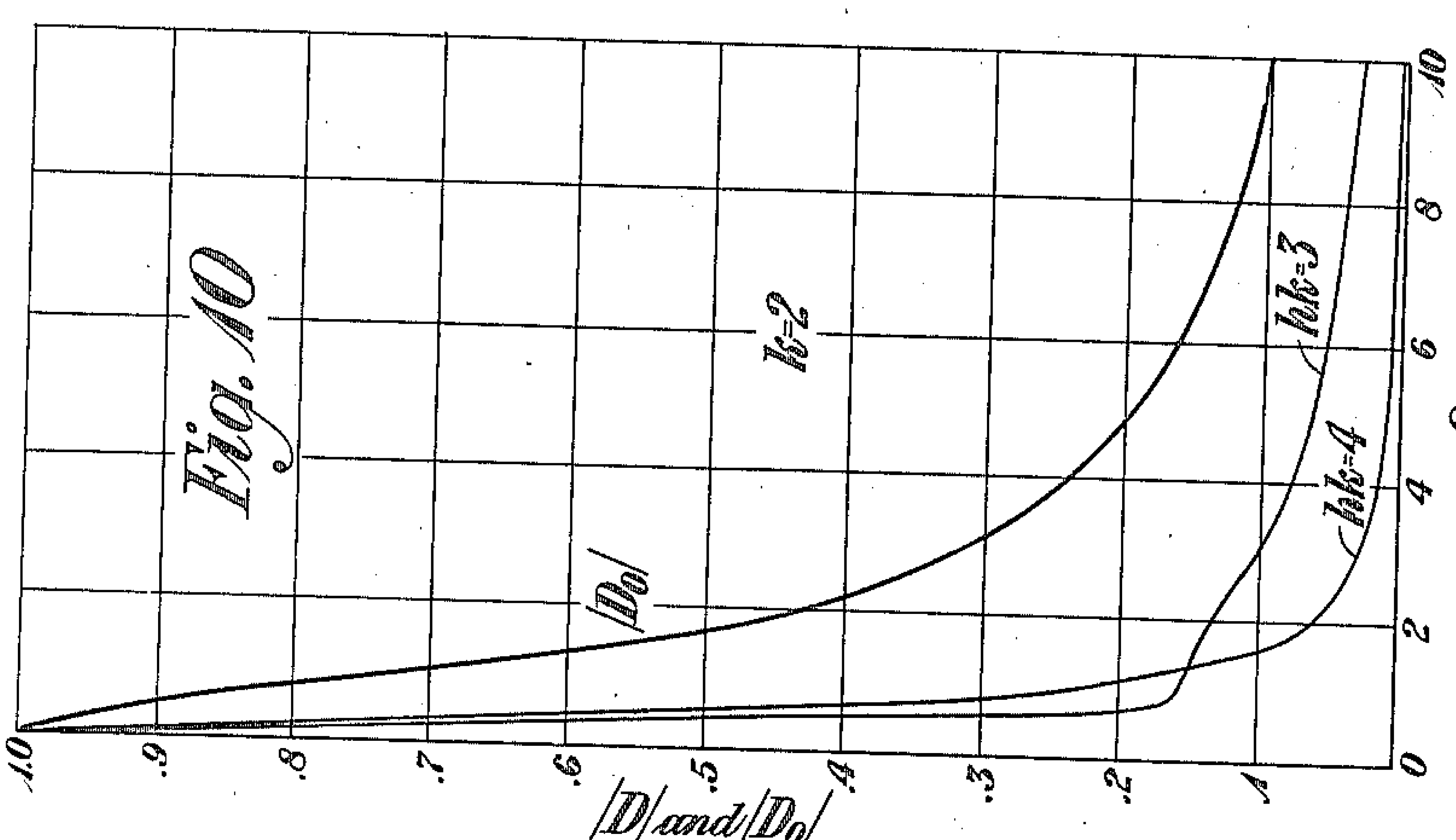

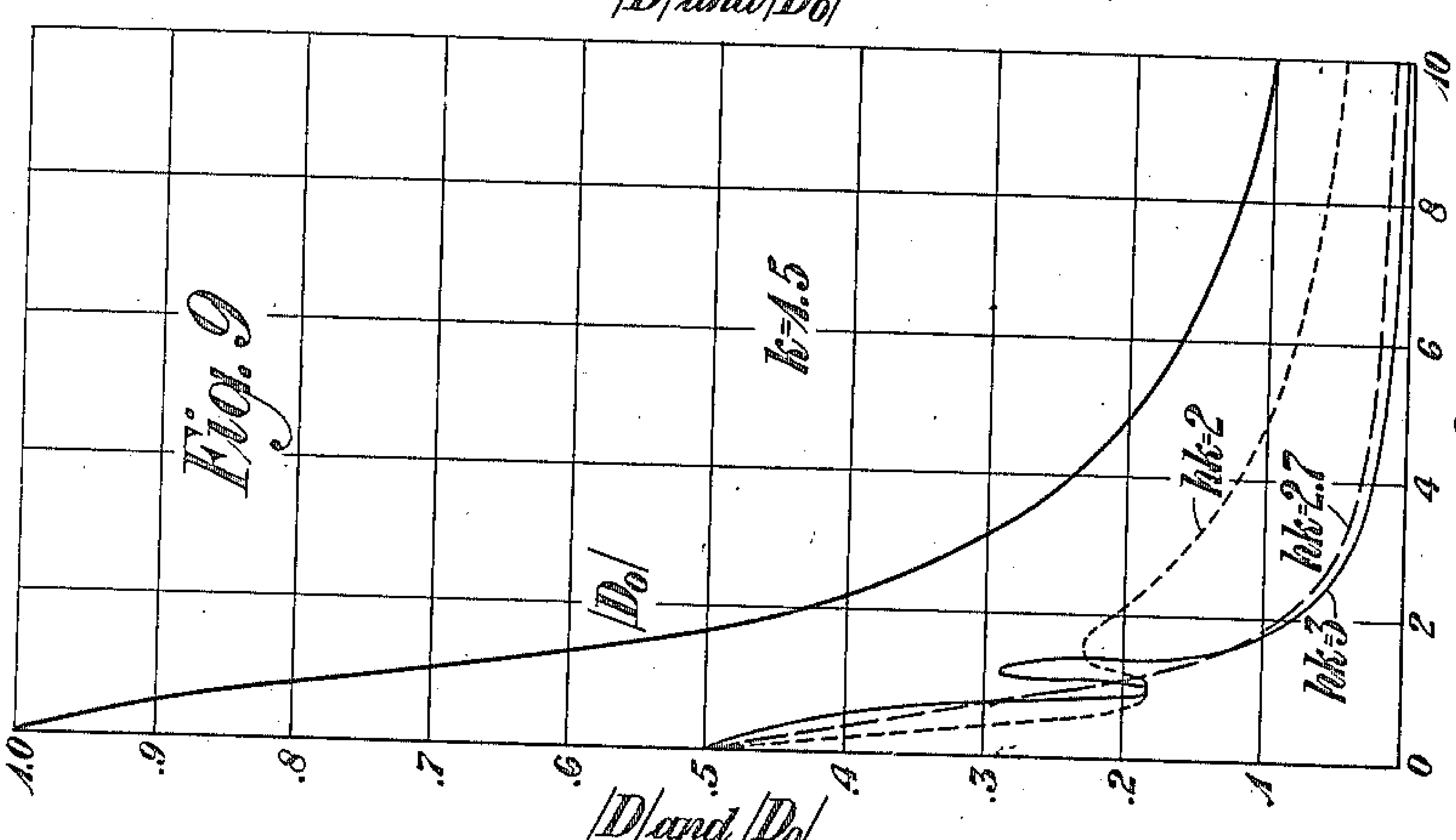

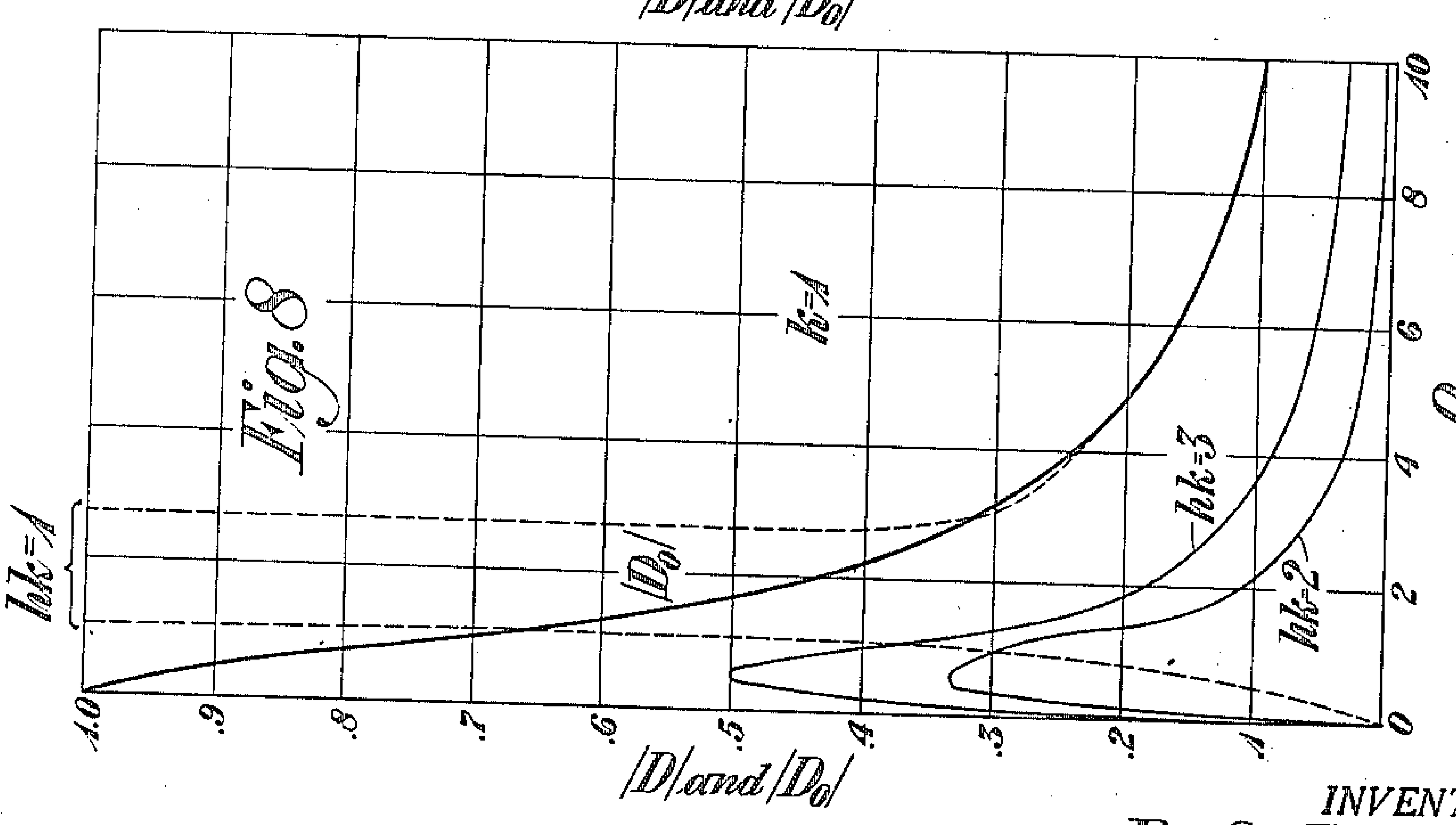

INVENTOR.
R. S. Hoyt
BY G. E. Folk.
ATTORNEY

Patented Oct. 3, 1922. 1,430,808

UNITED STATES PATENT OFFICE.

RAY S. HOYT, OF BROOKLYN, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

TWO-WAY IMPEDANCE EQUALIZER FOR TRANSFORMERS.

Application filed November 28, 1918. Serial No. 264,656.

To all whom it may concern:

Be it known that I, RAY S. HOYT, residing at Brooklyn, in the county of Kings and State of New York, have invented certain Improvements in Two-Way Impedance Equalizers for Transformers, of which the following is a specification.

This invention relates to a circuit arrangement, or network, to be associated with an electrical transformer system (that is, a transformer together with the two external impedances between which the transformer is connected). The object of this invention is to provide a simple network having such an electrical impedance that when said network is duly associated with the transformer system the resultant impedance of the combined system shall thereby be rendered closely equal to its ideal value, over a wide range of frequencies such, for instance, as the range of frequencies essential for the telephonic transmission of speech. The special name "impedance-equalizer" is here given to this network because the ideal value of the impedance of the transformer system would in the most important practical cases be approximately independent of frequency, while its actual value would vary considerably or greatly with frequency; so that the result then accomplished by the network would be the equalization of the impedance of the system with reference to frequency.

My invention is capable of many and varied uses but is of particular utility when associated with transformers occurring in a transmission system containing two-way repeaters.

This invention is in the nature of an improvement on that already disclosed in my Patent Serial No. 1,333,111, March 9, 1920. Said patent relates to a one-way equalizer adapted for equalizing the impedance for only one side of the transformer (either the primary side or the secondary side) and thus possessing the desired property only for transmission in one of the two directions. Such one-way equalization suffices in many applications, particularly in those involving only a single two-way repeater; but in many other applications, particularly those involving a plurality of two-way repeaters, two-way equalization, such as accomplished by my present invention, becomes important.

My invention is best understood by reference to the accompanying drawings, in which

Fig. 1 is a schematic diagram of an unequalized transformer system consisting of a transformer (J_1, J_2, J_{12}) and the two external impedances (R_1 and R_2) between which the transformer is connected; while Fig. 2 is the corresponding diagram of an equalized transformer system, Z_1 and Z_2 respectively denoting the impedances of the primary and secondary units which together compose the equalizer. These two diagrams—particularly that of Fig. 2—are here provided in order to assist in understanding the development of certain general underlying formulas employed below.

Figs. 3, 4, 5, 6 are diagrams of four different specific types of impedance-equalizers, constituting specific embodiments of my invention.

Figs. 7, 8, 9, 10 and 11 present a series of curves illustrating the precision of the impedance-equalization accomplished by the several types of equalizers above mentioned.

The general theory underlying the impedance-equalizers of this invention will now be developed, after which certain specific types will be disclosed and the appropriate design-formulas will be derived.

In Fig. 1, which represents an unequalized transformer system, J_1 and J_2 respectively denote the self-impedances of the primary and secondary windings of the transformer, and J_{12} denotes their mutual impedance; while R_1 and R_2 respectively denote the primary and secondary external impedances between which the transformer is connected. In practice one of these impedances may be that of a transmission line while the other may be that of a repeater.

For the purpose of developing the underlying general theory consider Fig. 2, which represents the system of Fig. 1 augmented by two impedances Z_1 and Z_2 in series with the primary and secondary circuits respectively. In the application of the general theory, Z_1 and Z_2 will represent the impedances of the two equalizer-units (the number of the equalizer units being two in order to admit of accomplishing impedance-equalization simultaneously in the two directions). Evidently, formulas expressing the properties of the unequalized system of Fig. 1 need not be separately developed, as they can be immediately deduced from the corresponding formulas for the system of Fig. 2 merely by setting Z_1 and Z_2 each equal to zero therein.

Because of the nature of the function to be performed by the impedance-equalizer we are concerned with the primary and with the secondary driving-point impedances of the system of Fig. 2; the primary driving-point impedance S_1 being the total impedance offered by the system to an E. M. F. inserted in the primary circuit when there is no other E. M. F. in the system; while the secondary driving-point impedance S_2 has a similar meaning with reference to the secondary circuit. In order to derive formulas for S_1 and S_2 suppose electromotive forces E_1 and E_2 inserted serially in the primary and secondary circuits, respectively; and let I_1 and I_2 denote the corresponding resulting currents. Then

$$\begin{aligned}(J_1+R_1+Z_1)I_1+J_{12}I_2&=E_1\\(J_2+R_2+Z_2)I_2+J_{12}I_1&=E_2\end{aligned}\quad(1)$$

which, solved for the ratios I_1/E_1 and I_2/E_2, give

$$I_1/E_1=\frac{J_2+R_2+Z_2-J_{12}E_2/E_1}{(J_1+R_1+Z_1)(J_2+R_2+Z_2)-J_{12}^2}\quad(2)$$

$$I_2/E_2=\frac{J_1+R_1+Z_1-J_{12}E_1/E_2}{(J_2+R_2+Z_2)(J_1+R_1+Z_1)-J_{12}^2}\quad(3)$$

S_1 being, by definition, the value of E_1/I_1 when $E_2=O$, we find from (2), by putting $E_2=O$ therein, that

$$S_1=J_1+R_1+Z_1-J_{12}^2/(J_2+R_2+Z_2)\quad(4)$$

Similarly, by putting $E_1=O$ in (3), we find that

$$S_2=J_2+R_2+Z_2-J_{12}^2/(J_1+R_1+Z_1)\quad(5)$$

In order to exhibit the need for an impedance-equalizer we shall apply the preceding general formulas to the unequalized system of Fig. 1 by setting Z_1 and Z_2 each equal to zero and denoting the corresponding values of S_1 and S^2 by S_1' and S_2' respectively, so that

$$\begin{aligned}S_1'&=J_1+R_1-J_{12}^2/(J_2+R_2)\quad(6)\\S_2'&=J_2+R_2-J_{12}^2/(J_1+R_1)\quad(7)\end{aligned}$$

These being similar to each other in form, it will suffice to discuss only one of them, say the formula for S_1'. This can be rewritten in the form

$$S_1'=R_1+\frac{J_1}{J_2}R_2-\frac{R_2/J_2}{1+R_2/J_2}\frac{J_1}{J_2}R_2+\frac{1-J_{12}^2/J_1J_2}{1+R_2/J_2}J_1\quad(8)$$

which, though in a sense more complicated than (6), possesses the advantage of exhibiting the physical relations more clearly. Thus, (8) shows that, for a transformer having no magnetic leakage,

$$S_1'=R_1+\frac{J_1}{J_2}R_2-\frac{R_2/J_2}{1+R_2/J_2}\frac{J_1}{J_2}R_2\quad(9)$$

the well-known condition for no magnetic leakage being $L_1L_2=L_{12}^2$, (see Bedell, "The principles of the transformer", 1896, page 197) which can be written very closely as $J_1J_2=J_{12}^2$.

That this approximation is warranted may be demonstrated as follows:

If the resistance components of the transformer impedances J_1, J_2, J_{12} be denoted by T_1, T_2, T_{12} then the complete and exact formulæ for J_1, J_2, J_{12} will evidently be

$$\begin{aligned}J_1&=T_1+ipL_1\\J_2&=T_2+ipL_2\\J_{12}&=T_{12}+ipL_{12}\end{aligned}$$

Now, for an efficient or even fairly efficient transformer the resistance components T_1, T_2, T_{12} are small compared with the reactance components ipL_1, ipL_2, ipL_{12}—corresponding to the well-known fact that for such a transformer the "magnetizing" current is nearly "wattless", and hence the angles of the transformer impedances are nearly 90°. Consequently we may write, $J_1=ipL_1$, $J_2=ipL_2$, and $J_{12}=ipL_{12}$. Since by the preceding equations, the impedance is approximately proportional to the inductance, the expression $J_1J_2=J_{12}^2$ may be substituted for the formula given by Bedell. If this value be substituted in the last term of equation 8, it will be seen that this term vanishes so that equation 8 becomes equation 9, as previously indicated.

Further, (8) shows that for an ideal transformer

$$S_1'=R_1+\frac{J_1}{J_2}R_2\quad(10)$$

an ideal transformer being one having infinite self and mutual impedances, no magnetic leakage (and also no dissipation). The limiting value of S_1' expressed by (10) may be termed the ideal value of S_1', as it is the value that would be attained by means of an ideal transformer; it consists merely of the sum of two simple terms the first of which is the primary external impedance, while the second is the secondary external impedance multiplied by the appropriate impedance-ratio of the transformer. From these considerations we now see on referring back to equation (8), which is the formula for the primary driving-point impedance of any actual transformer system, that the last term therein represents the effect of magnetic leakage and that the next to the last term represents the effect resulting from the impedance of the transformer-winding being finite rather than infinite, the ratio R_2/J_2 becoming zero only when J_2 becomes infinite (for any finite value of R_2).

Henceforth the external impedances R_1 and R_2 may be regarded as pure resistances; and the impedance ratio J_1/J_2 of the transformer (and hence its inductance ratio L_1/L_2) will be supposed equal to the ratio R_1/R_2 of the external resistances, this being the optimum value of J_1/J_2 in that the power transmitted through the transformer is then a maximum. That this is exactly true for an ideal transformer can be seen from equation (10), which shows that, when J_1/J_2 is equal to R_1/R_2, $S_1'-R_1$ is equal to R_1; in other words, that the effective resistance $S_1'-R_1$ to which the primary external resistance R_1 is connected has then a value equal to R_1, which is just the value to absorb maximum power from any electromotive force located in the primary external resistance having the fixed value R_1—it being well-known that any fixed source of electromotive force (whose impedance is pure resistance) will deliver maximum power into a receiver (whose impedance is pure resistance) when the resistance of the receiver is made equal to the resistance of the source. To prove this latter theorem, let E and R denote the (fixed) electromotive force and resistance of the source, r the resistance of the receiver, I the current, and P the power absorbed by r. Then

$$P = rI^2 = \frac{rE^2}{(r+R)^2}$$

which, for fixed E and R but variable r, can readily be shown (by differentiation, for instance) to be a maximum when r is made equal to R.

In applying this general theorem to the particular system consisting of R_1 and R_2 connected by a transformer, it is to be noted that the transformer has been regarded as ideal and hence as transmitting power without any dissipation. For an efficient or even fairly efficient actual transformer, this would still be closely true and hence the optimum value of L_1/L_2 closely equal to R_1/R_2—so closely, in fact, that this is ordinarily adopted as the optimum value and will thus be adopted in the presentation of the equalizer theory later herein.

If the transformer connecting R_1 and R_2 were ideal and had the optimum impedance ratio $J_1/J_2=R_1/R_2$, then by (10) the value of S_1 would be merely $2R_1$, and similarly the value of S_2' would be merely $2R_2$; and therefore the difference S_1-2R_1 and the difference S_2-2R_2 would each be zero. For an actual transformer, unequalized, these differences would be quite large over a considerable range of frequencies; for a transformer equipped with impedance-equalizers, the smallness of these differences would be a precision-measure of the degree of equalization accomplished. In practice it is convenient to take R_1 and R_2 as standards of reference in determining the relative magnitudes of S_1-2R_1 and S_2-2R_2; that is, the natural criteria as to the degree of equalization accomplished are the quantities D_1 and D_2 defined by the equations

$$D_1=(S_1-2R_1)/R_1 \quad (11)$$
$$D_2=(S_2-2R_2)/R_2 \quad (12)$$

which may conveniently be termed the "fractional deviations." In ordinary applications their absolute values $|D_1|$ and $|D_2|$, regarded as functions of the frequency, are the functions of chief significance in indicating the degree of equalization.

In ordinary practice the impedance-distortion due to the magnetic leakage of a transformer is quite small compared with the distortion due to its self and mutual impedances being finite rather than infinite. In what follows, magnetic leakage will therefore be neglected, as the discussion is thereby greatly simplified without introducing any substantial error. Introducing into (4) the condition $J_{12}^2=J_1J_2$ for no magnetic leakage, and substituting into (11) the resulting value of S_1, we find that

$$D_1=\frac{(J_1/R_1)(1+Z_2/R_2)}{1+Z_2/R_2+J_2/R_2}+\frac{Z_1}{R_1}-1 \quad (13)$$

Similarly

$$D_2=\frac{(J_2/R_2)(1+Z_1/R_1)}{1+Z_1/R_1+J_1/R_1}+\frac{Z_2}{R_2}-1 \quad (14)$$

Henceforth it will be assumed that the transformer has the proper inductance-ratio for securing maximum power transmitted, namely

$$L_1/L_2=R_1/R_2 \quad (15)$$

that is

$$L_1/R_1=L_2/R_2 \quad (16)$$

whence

$$J_1/R_1=J_2/R_2=iQ \quad (17)$$

where

$$Q=pL_1/R_1=pL_2/R_2 \quad (18)$$

Q thus being proportional to the frequency $f=p/2\pi$.

In harmony with (17) we may impose the relation

$$Z_1/R_1=Z_2/R_2=W,\ \text{say} \quad (19)$$

thus making the impedances of the respective equalizer units proportional to the total self-impedances of the circuits into which they are inserted.

In consequence of (17) and (19) the values of D_1 and D_2, given by (13) and (14) become equal; and their common value D is expressed by the formula

$$D=\frac{iQ(1+W)}{1+W+iQ}+W-1 \quad (20)$$

$$D=\frac{W^2-1+i2WQ}{1+W+iQ} \quad (21)$$

When the impedance-equalizer units are

omitted—which is evidently equivalent to putting $Z_1=Z_2=O$ in formulas (4) and (5), and hence $W=O$ in (20) and (21)—the corresponding value of D, which will be denoted by D_0, is expressed by the simple formula

$$D_0=-1/(1+iQ) \quad (22)$$

whence

$$|D_0|=1/\sqrt{1+Q^2} \quad (23)$$

On each of the drawings (cited below) which show the characteristics of the several specific types of equalizers disclosed, is included a graph of $|D_0|$ to serve as a standard of comparison to indicate the degree of impedance-equalization attained, D_0 being the value of D for the unequalized system.

Condenser type of equalizer.

The type of equalizer disclosed under this heading is one in which each equalizer-unit consists of a condenser, as represented in Fig. 3; where c_1 and c_2 denote the capacities of the primary and secondary units respectively. Hence $Z_1=-i/pc_1$ and $Z_2=-i/pc_2$; and therefore, by (19) and (17)

$$W=-i/hQ \text{ or } \frac{1}{W}=ihQ \quad (24)$$

where

$$h=c_1R_1^2/L_1=c_2R_2^2/L_2 \quad (25)$$

Substituting into (21) the value of W given by (24), we find that

$$D=\frac{(2-h)Q-i/hQ}{hQ+i(hQ^2-1)} \quad (26)$$

whence

$$|D|=\frac{(2-h)Q-1/hQ}{\sqrt{1-h(2-h)Q^2+h^2Q^4}} \quad (27)$$

As the result of a series of computations and plottings of $|D|$ as function of Q with h as parameter, I discovered that, for the range of ordinary practical applications, the best value for the parameter h is approximately 2; but of course my invention is not restricted to the employment of any particular value of h. Fig. 7 gives a graph of $|D|$ computed from (27) with $h=2$; also a graph of $|D_0|$—computed from (23)—which is the value of D when the equalizers are omitted. Comparison of these two graphs shows the very great improvement accomplished by the impedance-equalizer; the equalization being nearly complete except at such small values of Q as would usually be unimportant in practice.

With the value of the parameter h once chosen, the equalizer-elements are completely determined, the design-formulas being, by (25).

$$\begin{aligned} c_1&=hL_1/R_1^2 \\ c_2&=hL_2/R_2^2 \end{aligned} \quad (28)$$

Condenser-resistance type of equalizer.

The type of equalizer disclosed under this heading is one in which each equalizer-unit consists of a condenser shunted by a resistance as represented in Fig. 4; where c_1 and r_1 denote respectively the capacity and the resistance of the elements composing the primary unit, and c_2 and r_2 the capacity and resistance of the elements composing the secondary unit.

For this type of equalizer

$$\begin{aligned} Z_1&=r_1/(1+ipc_1r_1) \\ Z_2&=r_2/(1+ipc_2r_2) \end{aligned} \quad (29)$$

Hence, by (19) and (17)

$$W=k/(1+ihkQ) \quad (30)$$

where

$$h=c_1R_1^2/L_1=c_2R_2^2/L_2 \quad (31)$$

and

$$k=r_1/R_1=r_2/R_2 \quad (32)$$

In addition to the parameters h and k defined by (31) and (32), it is convenient to introduce a further parameter t defined by the equation $t=hk$, so that

$$t=c_1r_1R_1/L_1=c_2r_2R_2/L_2 \quad (33)$$

whence

$$W=k/(1+itQ) \text{ or } \frac{1}{W}=\frac{1}{k}+ihQ \quad (34)$$

Then, substituting into (20) the value of W given by (34), we find that

$$D=\frac{iQ(1+k+itQ)}{k+(1+iQ)(1+itQ)}+\frac{k}{1+itQ}-1 \quad (35)$$

from which the value of $|D|$ can be calculated for any chosen values of the parameters k and t. As the result of a series of computations and plottings of $|D|$ as function of Q with k and t as parameters, I discovered that, for the ordinary range of practical applications the best pairs of values are approximately those lying within the range covered by the following table:

k.	t.
1.0	2.0
1.5	2.7
2.0	4.0

The particular pair of values of k and t chosen for use in any specific application depends on the relative weighting assigned to $|D|$ as a function of Q. As a guide in the choosing of k and t, Figs. 8, 9 and 10 give sets of graphs of $|D|$, computed by means of (35), for the three pairs of values of k and t above tabulated. Comparison of these $|D|$-graphs with the $|D_0|$-graph shows the high degree of equalization attained.

It will be noted that the values of $|D|$ at small values of Q depend much more on

k than on t; this is in accord with (35) which shows that D is equal merely to $k-1$ at $Q=0$. Thus, by choosing k small, $\|D\|$ can be kept low or fairly low at small values of Q; this feature constitutes the principal advantage of this type of equalizer over the simple condenser type disclosed above.

With the parameters k and t once chosen, the equalizer elements are completely determined, the design-formulas being, by (32) and (33),

$$r_1=kR_1 \quad r_2=kR_2 \qquad (36)$$

$$c_1=tL_1/kR_1^2 \quad c_2=tL_2/kR_2^2 \qquad (37)$$

Condenser-inductance type of equalizer.

The type of equalizer disclosed under this heading is one in which each equalizer-unit consists of a condenser shunted by an inductance, as represented in Fig. 5; where c_1 and d_1 denote respectively the capacity and the inductance of the elements composing the primary unit, and c_2 and d_2 the capacity and inductance of the elements composing the secondary unit.

Probably the chief practical advantage of this type of equalizer over the simple condenser type would be in such applications as might require a by-pass for currents of very low frequency—in particular, direct currents; as the inductance-elements d_1 and d_2 constitute such by-passes and at the same time can be so proportioned as not to affect the equalization-characteristics materially.

For this type of equalizer

$$Z_1=ipd_1/(1-p^2c_1d_1) \quad Z_2=ipd_2/(1-p^2c_2d_2) \qquad (38)$$

Hence, by (19) and (17)

$$W=igQ/(1-hgQ^2) \qquad (39)$$

where

$$h=c_1R_1^2/L_1c_2R_2^2/L_2 \qquad (40)$$

and

$$g=d_1/L_1=d_2/L_2 \qquad (41)$$

It is convenient to introduce a further parameter b defined by the equation

$$b=1/\sqrt{gh},$$

so that

$$b=L_1/R_1\sqrt{c_1d_1}=L_2/R_2\sqrt{c_2d_2} \qquad (42)$$

whence

$$w=\frac{igQ}{1-(Q/b)^2} \text{ or } \frac{1}{W}=ihQ-\frac{i}{gQ} \qquad (43)$$

Thus b is equal to the particular value of Q at which $W=\infty$; that is, b is the particular value of Q at which each of the combinations (c_1, d_1) and (c_2, d_2) is anti-resonant.

Because of its length, the formula for D in terms of b, g, Q has been omitted here; it is immediately obtainable, of course, by substituting into (20) or (21) the value of W given by (43). Two graphs of $\|D\|$ computed in that way are given on Fig. 11 to illustrate the characteristics of this type of equalizer.

With the values of the parameters g and b once chosen, the equalizer-elements are completely determined, the design-formulas being, by (41) and (42)

$$c_1=L_1/b^2gR_1^2 \quad c_2=L_2/b^2gR_2^2 \qquad (44)$$

$$d_1=gL_1 \quad d_2=gL_2 \qquad (45)$$

Condenser-resistance-inductance type of equalizer.

The type of equalizer disclosed under this heading is one in which each equalizer-unit consists of three elements in parallel with each other; namely a condenser, a resistance, and an inductance, as represented by Fig. 6, where c_1, d_1, r_1 denote respectively the capacity, inductance and resistance of the elements comprising the primary unit, and c_2, d_2, r_2, those of the secondary unit.

This type of equalizer includes the practical advantage, possessed also by the condenser-inductance type, of offering but little obstruction to the flow of very low frequency currents, particularly direct currents. In addition, owing to its greater number of elements, it admits of a wider range of proportioning than the types disclosed above.

For this type of equalizer

$$1/Z_1=1/r_1+1/ipd_1+ipc_1=1/r_1+(1-p^2c_1d_1)/ipd_1 \qquad (46)$$

and an analagous formula for $1/Z_2$. Hence, by (19) and (17),

$$1/W=1/k+(1-hgQ^2)/igQ \qquad (47)$$

where

$$k=r_1/R_1=r_2/R_2 \qquad (48)$$

and

$$h=c_1R_1^2/L_1=C_2R_2^2/L_2 \qquad (49)$$

and

$$g=d_1/L_1=d_2/L_2 \qquad (50)$$

It is convenient to introduce a further parameter b defined by the equation

$$b=1/\sqrt{gh},$$

so that

$$b=L_1/R_1\sqrt{c_1d_1}=L_2/R_2\sqrt{c_2d_2} \qquad (51)$$

whence

$$\frac{1}{W}=\frac{1}{k}+\frac{1-(Q/b)^2}{igQ} \text{ or } \frac{1}{W}=\frac{1}{k}+ihQ-\frac{i}{gQ} \qquad (52)$$

Thus b is equal to the particular value of

Q at which each of the combinations (c_1, d_1) and (c_2, d_2) is anti-resonant; and at which, therefore, W is equal merely to k.

Because of its length, the formula for D in terms of k, b, g, Q has been omitted here; it is immediately obtainable, of course, by substituting into (20) or (21) the value of W given by (52).

With the values of the parameters k, g, b once chosen, the equalizer elements are completely determined, the design formulæ being, by (48), (50), and (51),

$$c_1 = L_1/b^2gR_1^2 \quad (55)$$
$$c_2 = L_2/b^2gR_2^2 \quad (56)$$
$$d_1 = gL_1 \quad (57)$$
$$d_2 = gL_2 \quad (58)$$
$$r_1 = kR_1 \quad (53)$$
$$r_2 = kR_2 \quad (54)$$

It will be noted that equation 52 is generic in that it gives the relations when capacity, resistance and inductance are included in the equalizers, as shown in Fig. 6. In this equation the term "$\frac{1}{k}$" relates to the resistance element of the equalizer, the term "ihQ" relates to the capacity element, and term "$\frac{i}{gQ}$" relates to the inductance element. If the resistance element is omitted, it is equivalent to making "k" equal to infinity. If the inductance element is omitted, it is equivalent to making "g" equal to infinity, and finally, if the capacity element is omitted, it is equivalent to making "h" equal to zero. In any case, when equalization has been obtained, the external impedance on the one side of the transformer should be substantially equal to the apparent impedance of the other external impedance as seen through the transformers and the associated impedance equalizers.

By associating equalizing impedances of the character above described with a transformer system comprising a transformer interposed between two external impedances, the impedance of the remainder of the system, as viewed from either external impedance, may be made substantially equal, over a considerable range of frequencies, to said external impedance. It will also be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. A transmission system comprising a transformer interposed between two external impedances, and equalizing impedance elements associated with each winding of the transformer, said equalizing impedance elements being so proportioned with reference to the external impedances and the self-inductances of the windings of the transformer, that if either external impedance be disconnected, the impedance of the remainder of the system will be substantially equal, over a considerable range of frequencies, to that of the disconnected external impedance.

2. A transmission system comprising a transformer interposed between two external impedances, and equalizing impedance elements associated with each winding of the transformer, said equalizing impedance elements being so proportioned with reference to the external impedances and the constants of the transformer, that if either external impedance be disconnected, the impedance of the remainder of the system will be substantially equal, over a considerable range of frequencies, to that of the disconnected external impedance.

3. A transmission system comprising a transformer interposed between two external impedances, and equalizing impedance elements including a capacity associated with each winding of the transformer, said equalizing impedance elements being so proportioned with reference to the external impedances and the self inductances of the windings of the transformer that if either external impedance be disconnected, the impedance of the remainder of the system will be substantially equal, over a considerable range of frequencies, to that of the disconnected external impedance.

4. A transmission system comprising a transformer interposed between two external impedances, and equalizing impedance elements including a capacity associated with each winding of the transformer, said equalizing impedance elements being so proportioned with reference to the external impedances and the constants of the transformer that if either external impedance be disconnected, the impedance of the remainder of the system will be substantially equal, over a considerable range of frequencies, to that of the disconnected external impedance.

5. A transmission system comprising a transformer interposed between two external impedances, and equalizing arrangements associated with each winding of the transformer, said equalizing arrangements including a capacity in parallel with an impedance element, said equalizing arrangements being so proportioned with reference to the external impedances and the self-inductances of the windings of the transformer, that if either external impedance be disconnected, the impedance of the remainder of the system will be substantially equal, over a considerable range of frequencies, to that of the disconnected external impedance.

6. A transmission system comprising a transformer interposed between two external impedances, and equalizing arrangements

associated with each winding of the transformer, said equalizing arrangements including a capacity in parallel with an impedance element, said equalizing arrangements being so proportioned with reference to the external impedances and the constants of the transformer, that if either external impedance be disconnected, the impedance of the remainder of the system will be substantially equal, over a considerable range of frequencies, to that of the disconnected external impedance.

7. An arrangement to associate circuits of unequal impedances comprising a transformer, an impedance element in the primary circuit of the transformer and an impedance element in the secondary circuit of the transformer, these impedance elements being so proportioned respectively that the impedance of either associated circuit is substantially equal over a considerable frequency range to the impedance of the other associated circuit as seen when looking through the transformer towards the said other impedance.

8. In combination, a transformer comprising primary and secondary windings, circuits associated with each of said windings, and means associated with each of said windings whereby the impedance of each of said associated circuits is rendered substantially equal over a wide frequency range to the impedance of the other associated circuit as seen when viewed through the transformer and the associated means.

9. A transmission system comprising a transformer interposed between two external impedances, an equalizing impedance associated with each winding of the transformer, said equalizing impedances including a resistance in parallel with the capacity, the values of these two being adjusted with respect to each other and to the constants of the transformer and the external impedances in accordance with the relation

$$\frac{1}{W}=\frac{1}{k}+ihQ.$$

In testimony whereof I have signed my name to this specification this twenty-fifth day of November, 1918.

RAY S. HOYT.