Jan. 5, 1926. 1,568,145

H. W. ELSASSER

FREQUENCY FILTER FOR ELECTRIC CURRENTS

Filed Feb. 26, 1921 3 Sheets-Sheet 1

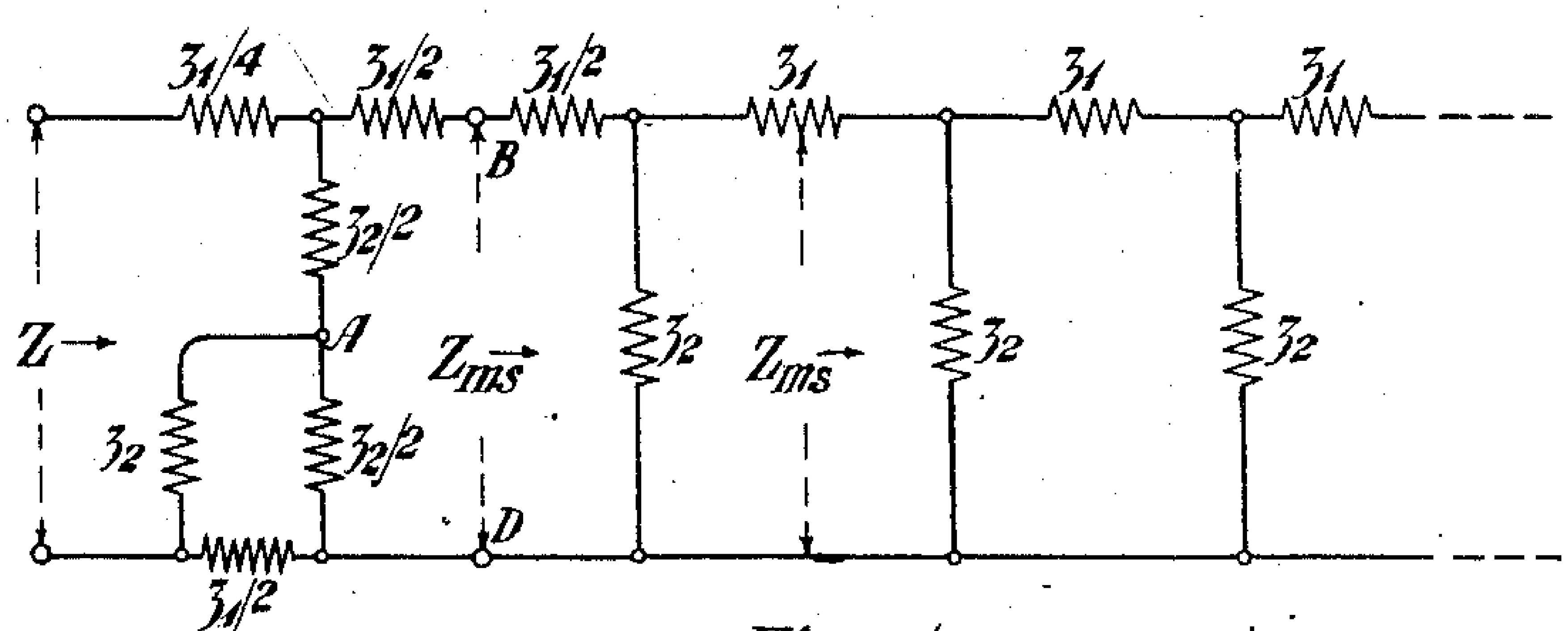


Fig. 1

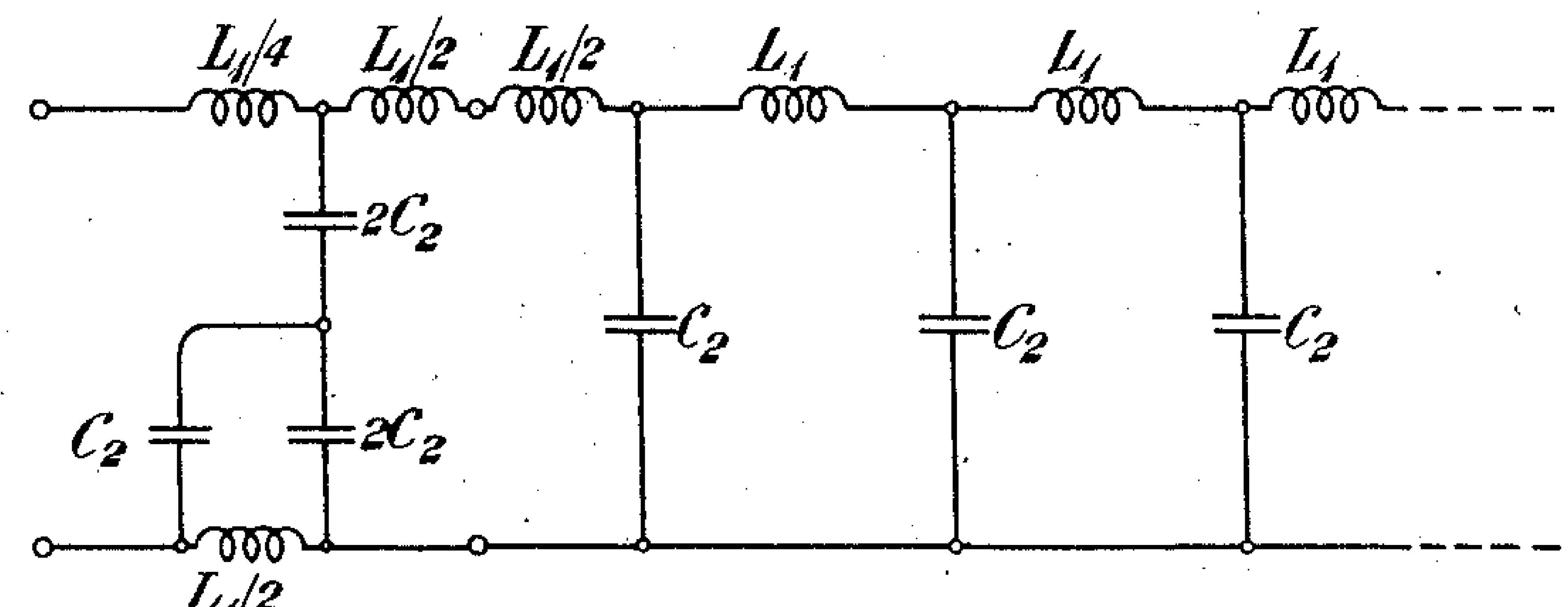


Fig. 2

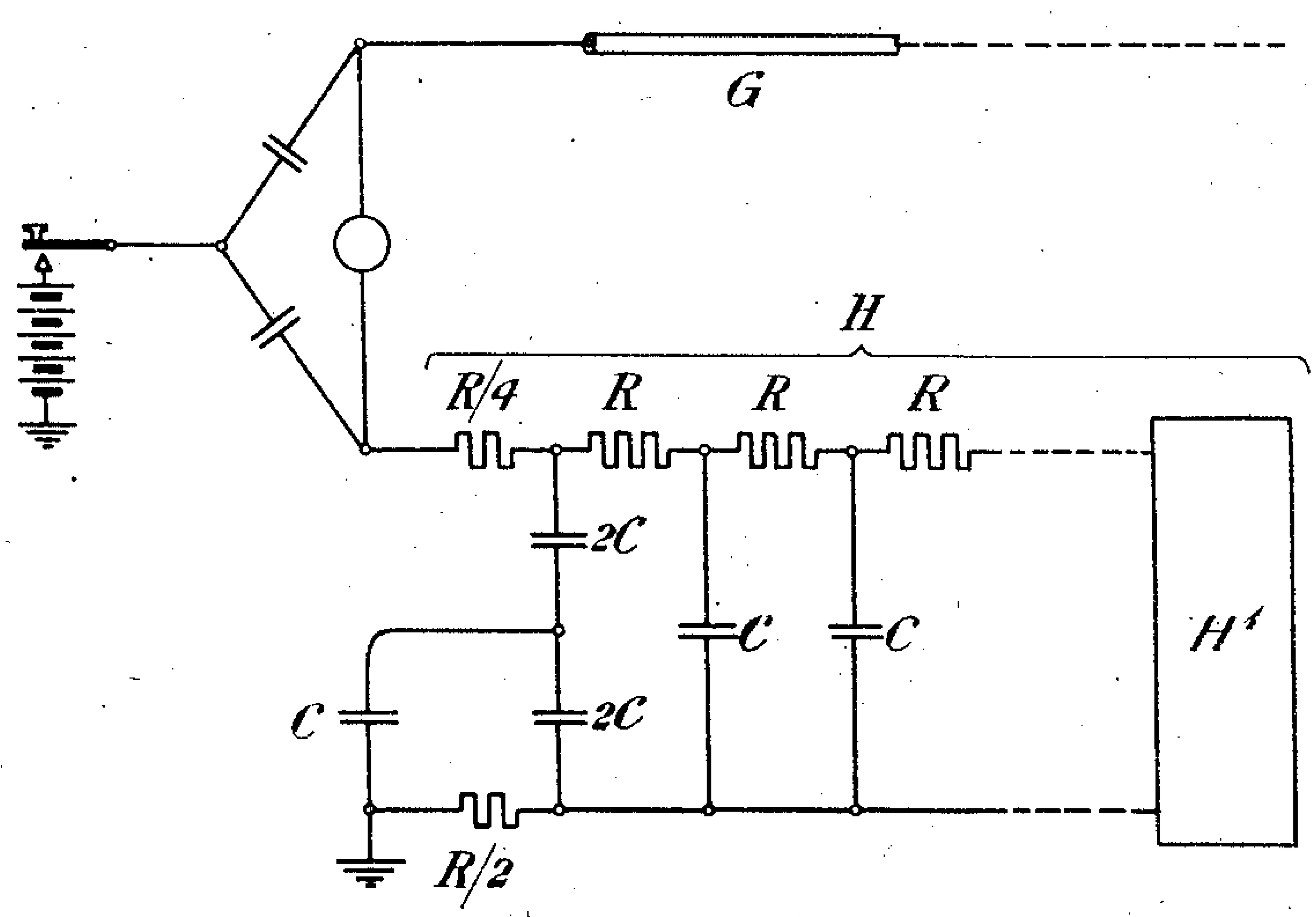


Fig. 3

Inventor
H.W. Elsasser
By his Attorney.

Jan. 5, 1926. **1,568,145**

H. W. ELSASSER

FREQUENCY FILTER FOR ELECTRIC CURRENTS

Filed Feb. 26, 1921 3 Sheets-Sheet 2

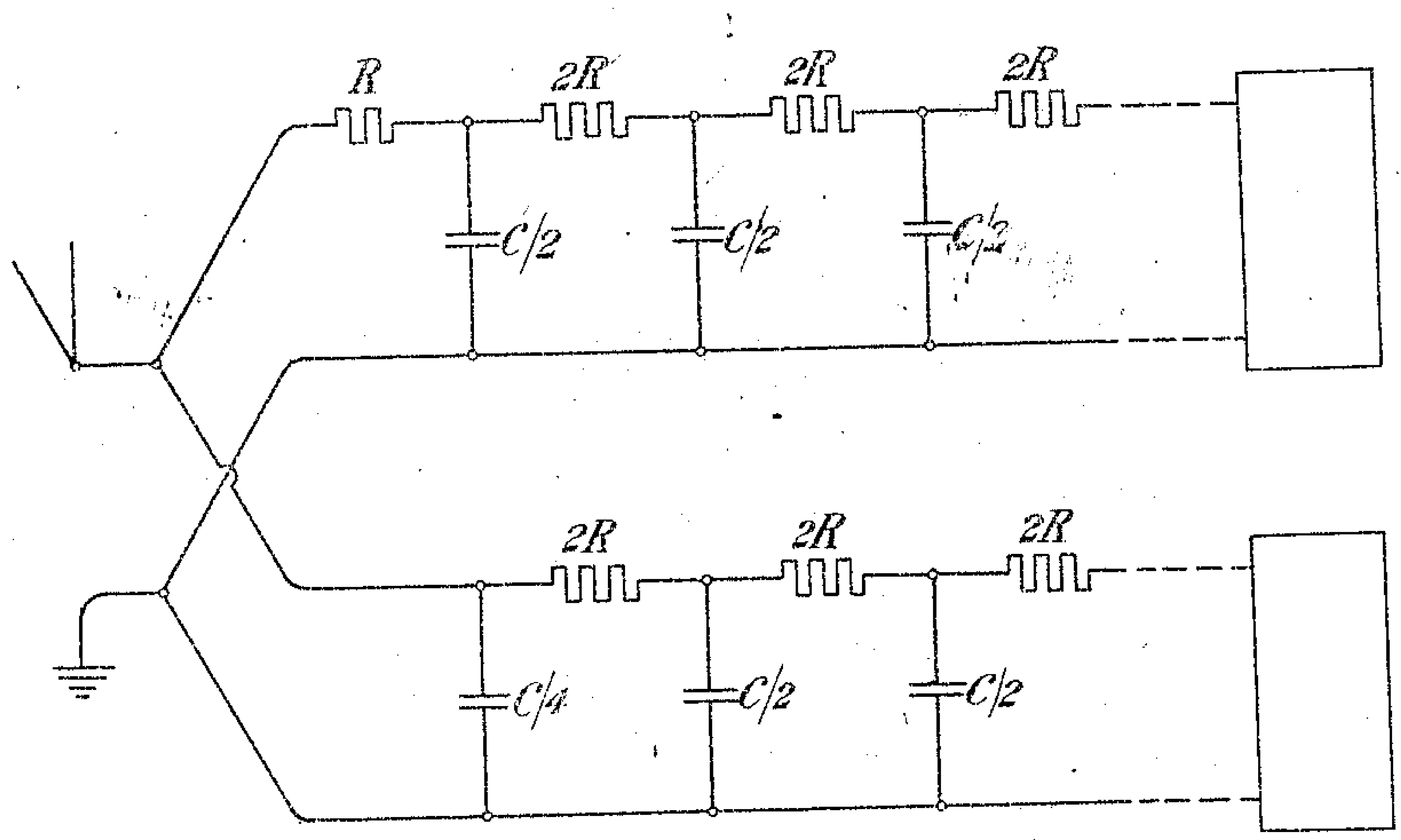


Fig. 4

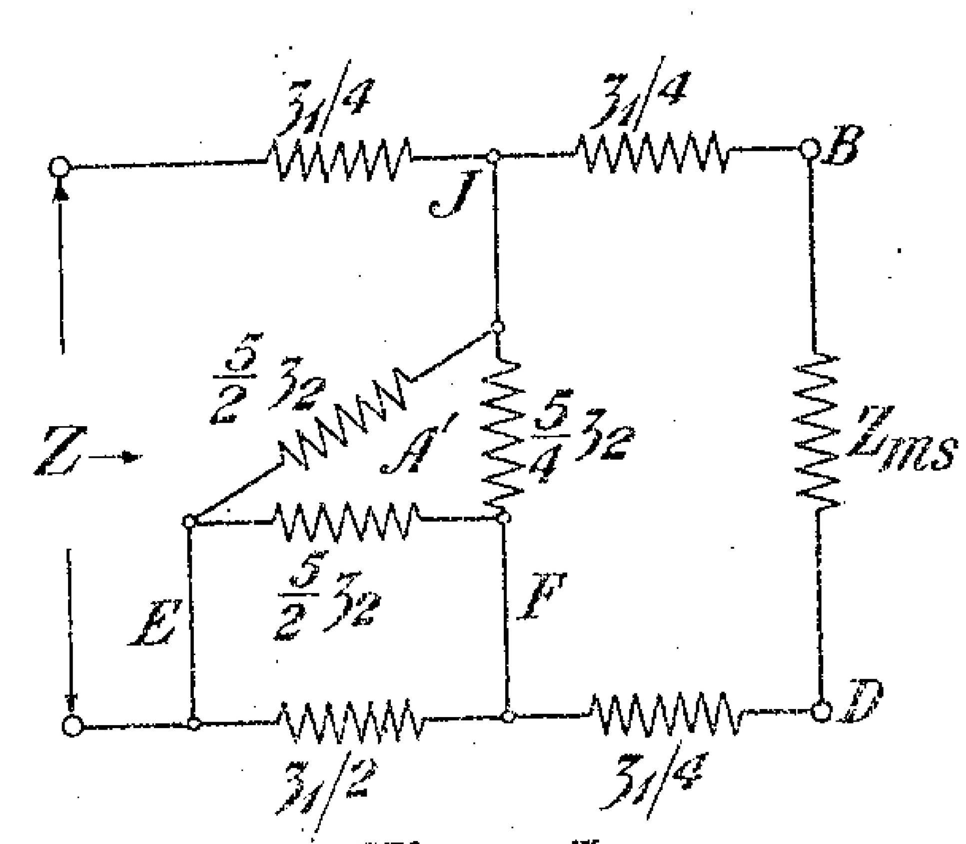


Fig. 5

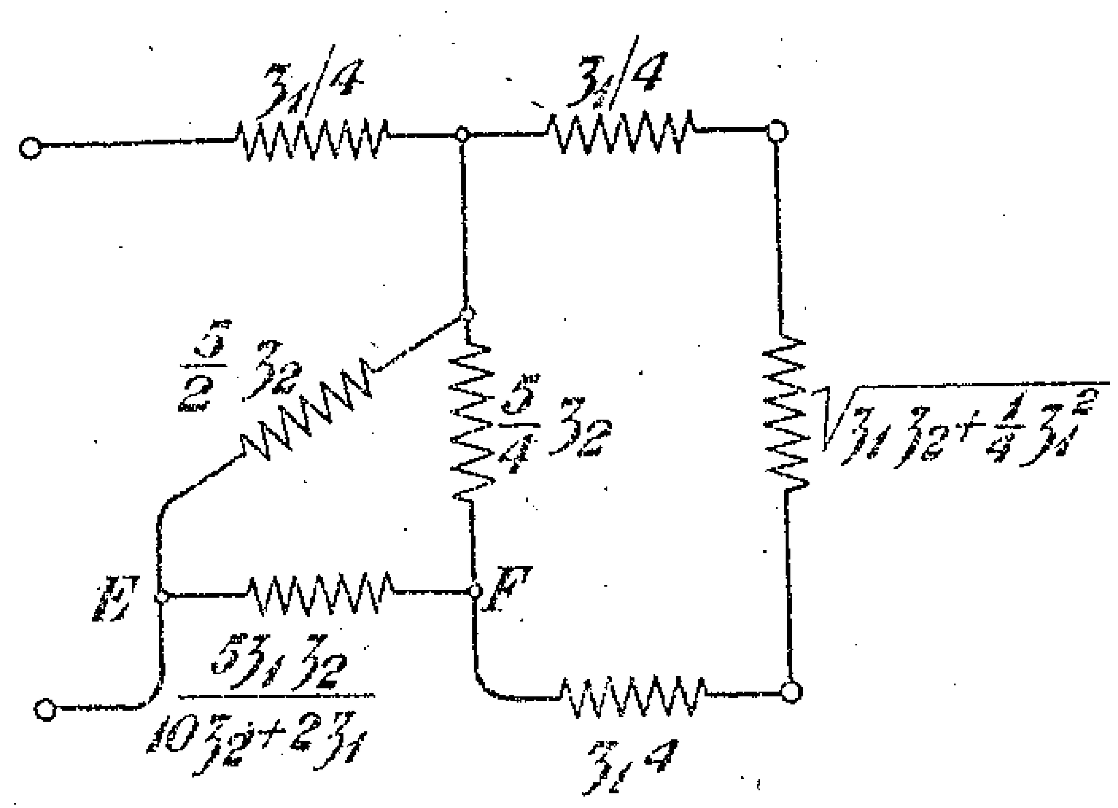


Fig. 6

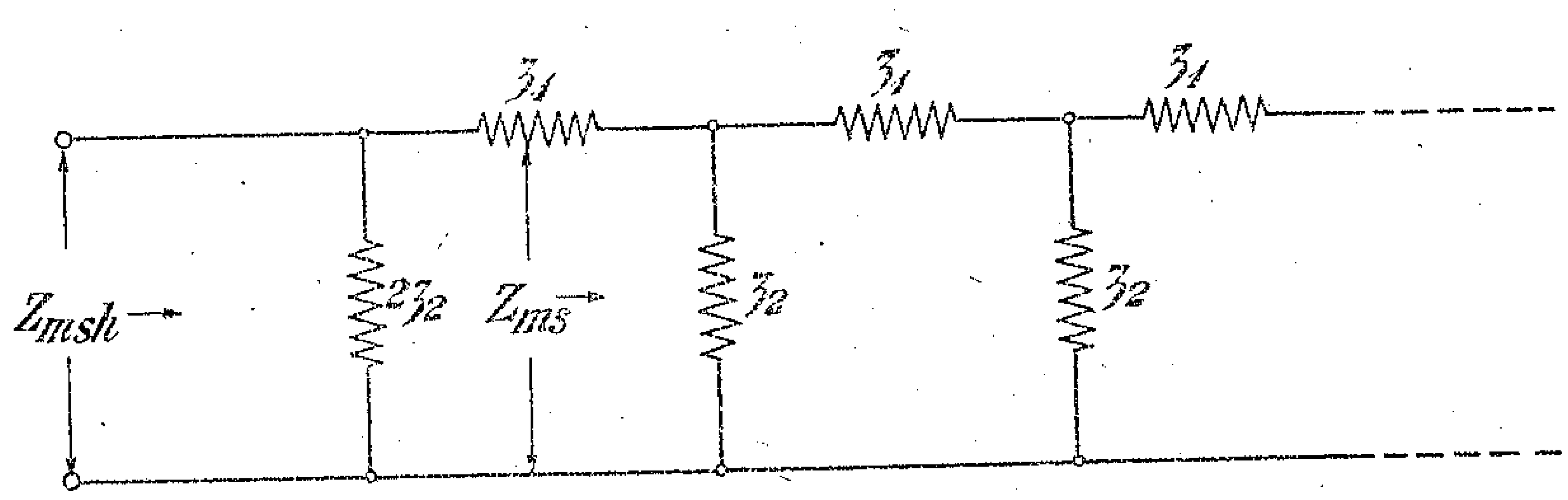


Fig. 7

Inventor
H. W. Elsasser

By his Attorney

Jan. 5, 1926. 1,568,145

H. W. ELSASSER

FREQUENCY FILTER FOR ELECTRIC CURRENTS

Filed Feb. 26, 1921 3 Sheets-Sheet 3

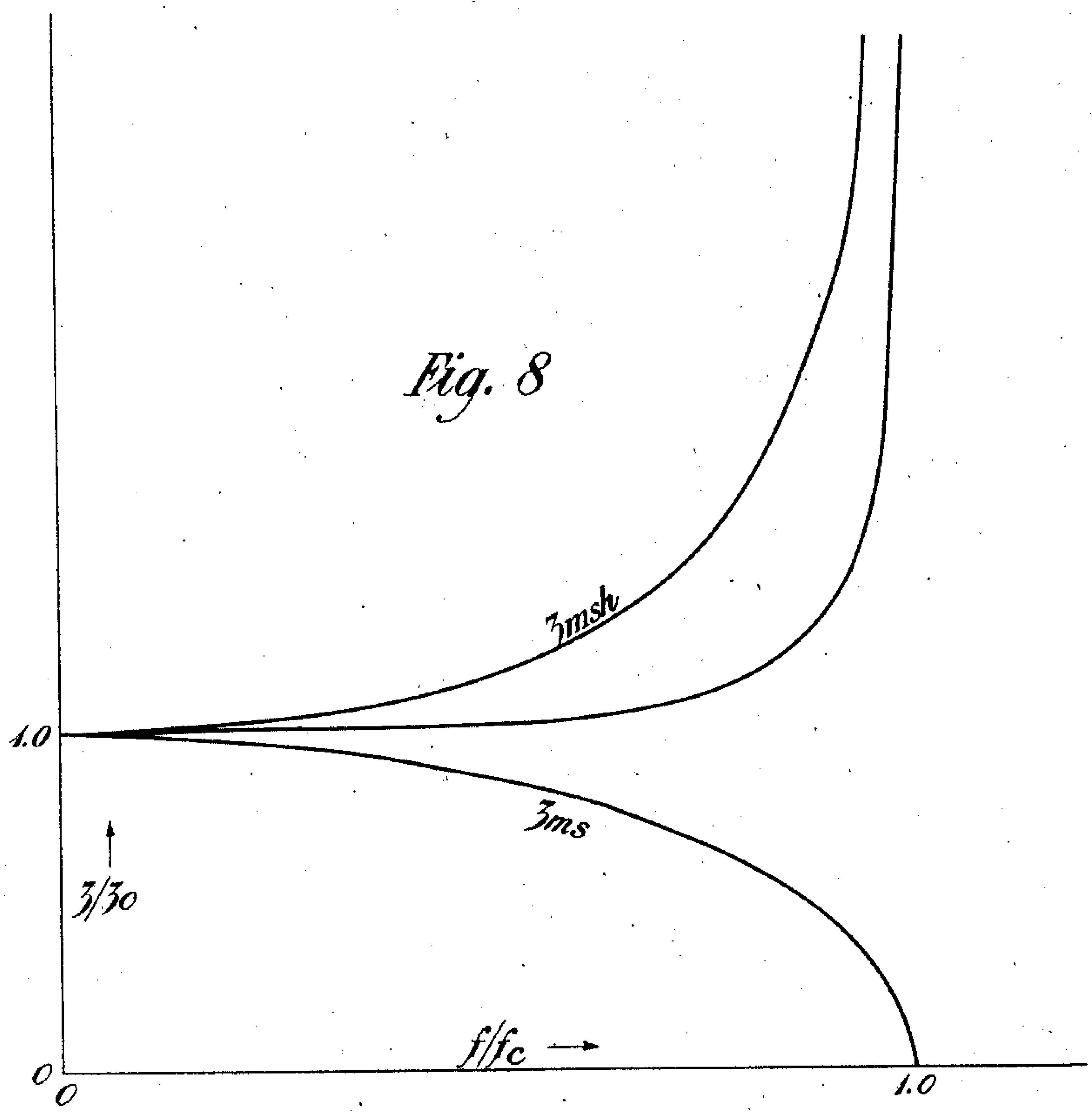
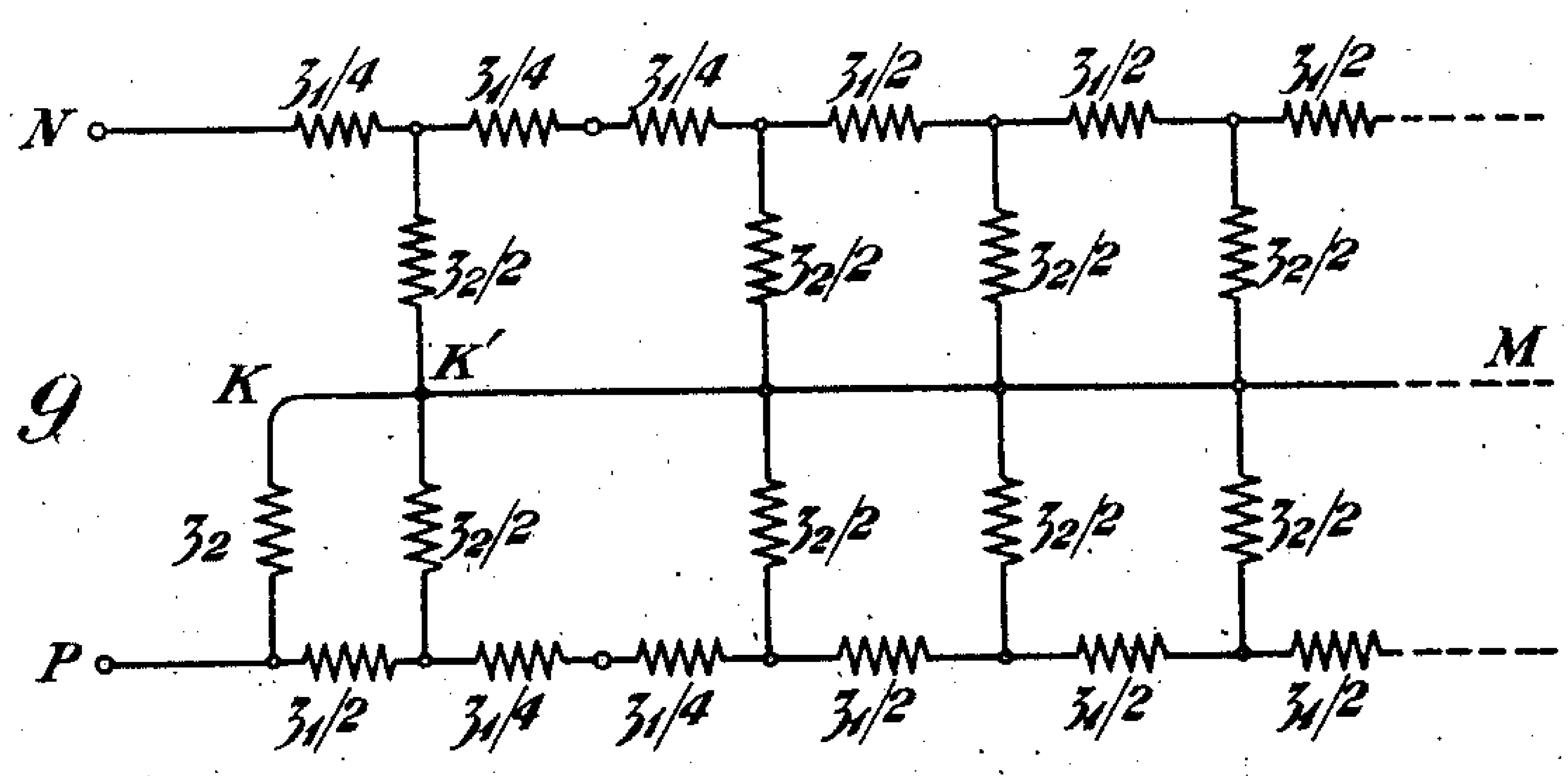


Fig. 9



Inventor
H. W. Elsasser
By his Attorney
G. E. Folk

Patented Jan. 5, 1926. **1,568,145**

UNITED STATES PATENT OFFICE.

HENRY W. ELSASSER, OF NEW YORK, N. Y., ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

FREQUENCY FILTER FOR ELECTRIC CURRENTS.

Application filed February 26, 1921. Serial No. 448,029.

To all whom it may concern:

Be it known that I, HENRY W. ELSASSER, a citizen of the United States, residing at New York, in the county of New York and State of New York, have invented certain Improvements in Frequency Filters for Electric Currents, of which the following is a specification.

It is an object of my invention to provide a new and improved wave filter for alternating currents of various frequencies. Another object of my invention is to provide an input termination for a filter of known type, so that the filter thus terminated shall have a substantially constant impedance over the free transmission range of frequencies, or over the most essential part of such range. Still another object of my invention has relation to providing an improved balancing network for ocean cable operation.

In the following specification, taken with the accompanying drawings, I have disclosed a limited number of specific embodiments of the invention and I now proceed to describe those embodiments, with the understanding that the invention will be defined in the appended claims.

In the drawings, Figure 1 is a diagram of a wave filter, or other artificial line, with my improved input terminal network combined therewith; Fig. 2 is a similar diagram for a filter of special type, that is, a so-called "low-pass" filter; Fig. 3 is a diagram showing how my invention may be embodied in the construction of an artificial line to balance an ocean cable; Fig. 4 is a diagram illustrating a modification of the apparatus shown in Fig. 3; Fig. 5 and Fig. 6 are diagrams for comparison with Fig. 1 in connection with the explanation of the theory thereof; Fig. 7 is a diagram that will be referred to when occasion arises to discuss the mid-shunt characteristic impedance of a filter; or other recurrent network; Fig. 8 is a diagram by the aid of which my improved filter may be compared with other types with respect to its equality of substantial constancy of impedance and Fig. 9 is a diagram for comparison with Fig. 1 in connection with the explanation of the theory of the apparatus of Fig. 1.

As is known, there is a class of artificial lines, each of which consists of a network of recurrent sections as in Fig. 1, where Z_1 is a series impedance, Z_2 is a shunt impedance, and the combination of these two impedances is repeated successively in the structure from left to right. The theory of such a network may be developed for an infinite number of sections extending from a given pair of terminals such as B and D in Fig. 1. In practice, a moderate finite number of sections will behave almost like the infinite network and the practical filter or other artificial line consists of such a finite number of sections with suitable terminal modifications.

Stated briefly and generally, such a network, functioning as a filter transmits freely currents of a frequency lying within a certain range and shunts out currents of a frequency lying in another range.

At the input end the filter may be terminated at any fractional point of a series element or of a shunt element. In Fig. 1, the filter begins at the terminals B and D in mid-series termination, which means that the first series impedance is only half the regular value, all the shunt impedances being the same. Having given the filter proper, extending to the right from terminals B and D as shown in Fig. 1, I will now call attention to my improved input terminal network. This consists of the various impedances having the values $Z_1/4$, $Z_1/2$, $Z_2/2$ and Z_2, disposed and connected as shown in the diagram. The effect of this net interposed at the input end of the filter is to make the impedance of the combination substantially constant over the free transmitting range, or more nearly constant than it would be without the net. That this is the effect of the interposed network will be demonstrated presently.

A more specific illustration is given in Fig. 2, where the filter is of the "low pass" type, meaning that it freely transmits all frequencies up to a certain critical value of frequency, but shunts out currents of higher frequency. In the low pass filter, the series impedances Z_1 are simply the impedances of the induction coils L_1 and the shunt impedances Z_2 correspond to the reactances of the shunt condensers C_2. The construction of the network will be apparent from Fig. 2 and it will be understood that the condensers of capacity $2C_2$ correspond to the impedances $Z_2/2$ of Fig. 1.

The problem of balancing a long ocean cable is one of considerable importance, for such cables are always operated by the bridge method, which requires an artificial line whose impedance should be essentially the same as that of the cable for a considerable range of frequencies. Fig. 3 shows the usual bridge at one end of the cable G, balanced against the artificial line or network H. This consists of an artificial balancing network of known type designated H′, connected through a few sections of the artificial line having my improved input termination as shown in the diagram, where the construction is so fully shown as not to require verbal exposition.

In Fig. 4, a somewhat different arrangement of the balancing network for the cable has been shown. The theory of these networks will be understood after explanation of the general theory has been given.

As I have stated, an advantage of my improved filter and terminal network is that they have a nearly constant impedance over the free transmitting range. To show this, I will compare their impedance over this range with the impedance of the same filter but with the common mid-series or mid-shunt termination, which has heretofore been employed. The mid-series termination is the one shown for the filter at the terminals B and D in Fig. 1, as already explained. The mid-shunt termination is shown in Fig. 7 where it will be apparent that the filter begins with a shunt element of half the usual admittance, that is, with the impedance $2Z_2$, the series elements all being equal and the remaining shunt elements all being equal but having the impedance value Z_2.

The mid-series characteristic impedance across the terminals B and D in Fig. 1 is, of course, the same in the infinite filter as across any other mid-series points. Hence we have the following equation:

$$Z_{ms}=\frac{Z_1}{2}+\cfrac{1}{\cfrac{1}{Z_2}+\cfrac{1}{\cfrac{Z_1}{2}+Z_{ms}}},$$

the solution of which gives

$$Z_{ms}=\sqrt{Z_1 Z_2+\frac{Z_1^2}{4}}. \quad (1)$$

Having obtained an expression for the value of the mid-series characteristic impedance Z_{ms}, it will now be shown that we can substitute for Fig. 1 the simpler finite diagram of Fig. 5. For the star at A in Fig. 1, I substitute the equivalent delta A′ in Fig. 5, comprising the three impedances $5Z_2/2$, $5Z_2/4$ and $5Z_2/2$. These values are obtained by the well known "star-delta" transformation, as explained, for example, in paragraph 34 and context, § 2 of the "Standard Handbook for Electrical Engineers," 4th edition, published in 1915 by the McGraw-Hill Book Company.

With this explanation, a mere inspection of the diagrams will show the validity of the substitution of Fig. 5 for Fig. 1 in the problem of obtaining the value of Z. Fig. 6 represents a further stage where the two parallel impedances between the points E and F are combined into the single impedance $5Z_1Z_2/(10Z_2+2Z_1)$.

By combining the parallel branches between J and F in Fig. 6, then between J and E, and representing the product Z_1Z_2 by Z_0^2 and the quotient Z_1/Z_2 by g^2, the result is reached by ordinary procedure, that

$$Z=\frac{Z_0}{2}\cdot\frac{(25g+11g^3+g^5)+\sqrt{1+g^2/4}\,(20+18g^2+2g^4)}{10+10g^2+2g^4+\sqrt{1+g^2/4}\,(12g+4g^3)} \quad (2)$$

At this point I will digress briefly to develop a value of Z_0 to be substituted therefor. Making use of the symbols Z_0 and g that have just been defined, it follows from Equation 1 that

$$Z_{ms}=Z_0\sqrt{1+\frac{g^2}{4}}. \quad (3)$$

In connection with Fig. 7, it will readily be seen that

$$Z_{msh}=\cfrac{1}{\cfrac{1}{2Z_2}+\cfrac{1}{\cfrac{Z_1}{2}+Z_{ms}}}$$

whence

$$Z_{msh}=Z_0\frac{1}{\sqrt{1+\frac{1}{4}g^2}} \quad (4)$$

Adding Equations 3 and 4, the result is obtained that

$$Z_0=(Z_{ms}+Z_{msh})\frac{\sqrt{1+\frac{g^2}{4}}}{2+\frac{g^2}{4}}$$

Substituting this value of Z_0 in Equation 2 gives

$$Z=\frac{Z_{ms}+Z_{msh}}{2}\cdot\frac{(25g+11g^3+g^5)\sqrt{1+\frac{1}{4}g^2}+(20+23g^2+\frac{13}{2}g^4+\frac{1}{2}g^6)}{(24g+11g^3+g^5)\sqrt{1+\frac{1}{4}g^2}+(20+\frac{45}{2}g^2+\frac{13}{2}g^4+\frac{1}{2}g^6)} \quad (5)$$

The foregoing Equation 5 is an expression for the impedance Z of the combined filter and terminal network of Fig. 1, in convenient form for demonstration of the substantial constancy of the value of Z.

In the applications that are of practical interest, the absolute value of g is always less, usually much less, than unity. Thus in the wave filter $g<1$ for the free transmitting range and the inequality is the more decided over that part of the range that is most useful. Accordingly in Equation 5 we may neglect powers of g higher than the first and write

$$Z=\frac{Z_{ms}+Z_{msh}}{2}\cdot\left(1+\frac{g}{20+24g}\right) \quad (6)$$

From Equation 3, it will be seen that as g departs from zero, Z_{ms} increases from Z_0; and from Equation 4 it will be seen that at the same time Z_{msh} decreases from Z_0. For the particular case of Fig. 2, these facts are shown by the diagram of Fig. 8. In this case, the abscissæ are frequency ratios instead of values of g, but this will be readily appreciated when it is understood that for the low-pass filter of Fig. 2,

$$g^2=\frac{Z^1}{Z^2}=i2\pi fL_1/\frac{-i}{2\pi fC_2}=-4\pi^2L_1C_1\cdot f^2$$

Thus it will be seen that not only in the particular case involved in Figs. 2 and 8, but in general, Z is more nearly constant (and equal to Z_0) than is either Z_{ms} or Z_{msh}. For frequencies near the end of the free transmission range, opposite to that for which $Z=Z_0$, the deviation evidently becomes considerable but it is a deviation that gives the filter as a whole an increasing impedance, so that its only effect is somewhat to hasten and blur the point of cut-off at the corresponding end of the frequency range.

The mid-series and mid-shunt terminations for which the impedances are represented by Z_{ms} and Z_{msh} are common filter terminations; it will be seen that compared with these terminations, my improved termination gives a more nearly constant impedance over the free transmitting range of frequencies.

A helpful view of the improvement may be afforded by consideration of Fig. 9, for which the structure is apparent. The conductor extending from K to M being considered to have zero resistance, the diagram evidently exhibits two filters in series, the first lying between the terminals N and K—M and the second between K—M and P. The first of these two filters has mid-series termination, the second mid-shunt. Their combined impedance across the terminals N and P is $Z_{ms}'+Z_{msh}'$.

Replacing Z_1 and Z_2 by $Z_1/2$ and $Z_2/2$ in Equations 1 and 4, the combined impedance of the network of Fig. 9 is found to be $\frac{1}{2}(Z_{ms}+Z_{msh})$. By the same course of reasoning presented heretofore in connection with Fig. 8, the impedance of the network of Fig. 9 is more nearly constant than is the impedance of either of its two component filters which are connected in series. Equation 6 amounts to a demonstration that the resistanceless connector K—M may be omitted between points K' and M. For some purposes, it may be preferable to keep the connections the same as in Fig. 9 instead of as in Fig. 1.

Whereas Fig. 9 represents the two filters of respective mid-series and mid-shunt termination connected in series, Fig. 4 shows two such artificial lines connected in parallel. Here again the resultant impedance across the terminals of the combination averages the impedances of the component elements and gives a more nearly constant value.

I claim:

1. A wave filter of the recurrent section type and a network at the input end consisting of a midseries input network and a midshunt input network connected in series between the input terminals and across the main body of the said filter whereby the filter has an impedance value approximately the average of the values that it would have with each termination alone.

2. A filter of the recurrent section type having two input terminals and an input terminal network comprising two series impedances connected respectively to the two terminals of the filter, and an impedance star with one ray resting connected with an intermediate tap in one of said series impedances and the other rays connected to the respective terminals of the other series impedance.

3. A wave filter of the type having recurrent sections extending from a pair of input

terminals, said filter being the equivalent of two filters with their input terminals connected in series, one of them having a midseries termination at the input end and the other having a midshunt termination at the input end whereby the impedance of the filter as a whole averages the impedances that would be obtained if the filter had either of said terminations alone.

4. A wave filter of the recurrent network type, two input terminals therefor, respective impedance elements connecting said filter with said terminals and a three terminal mesh with one terminal associated with one said impedance element and the other two terminals associated with the other said impedance element.

5. A wave filter of the type having recurrent sections and having its impedance made substantially constant over a considerable frequency range, this result being secured by an input terminal network combining the properties of a midseries ending and a midshunt ending.

In testimony whereof, I have signed my name to this specification this 18th day of February 1921.

HENRY W. ELSASSER.