

June 21, 1927.

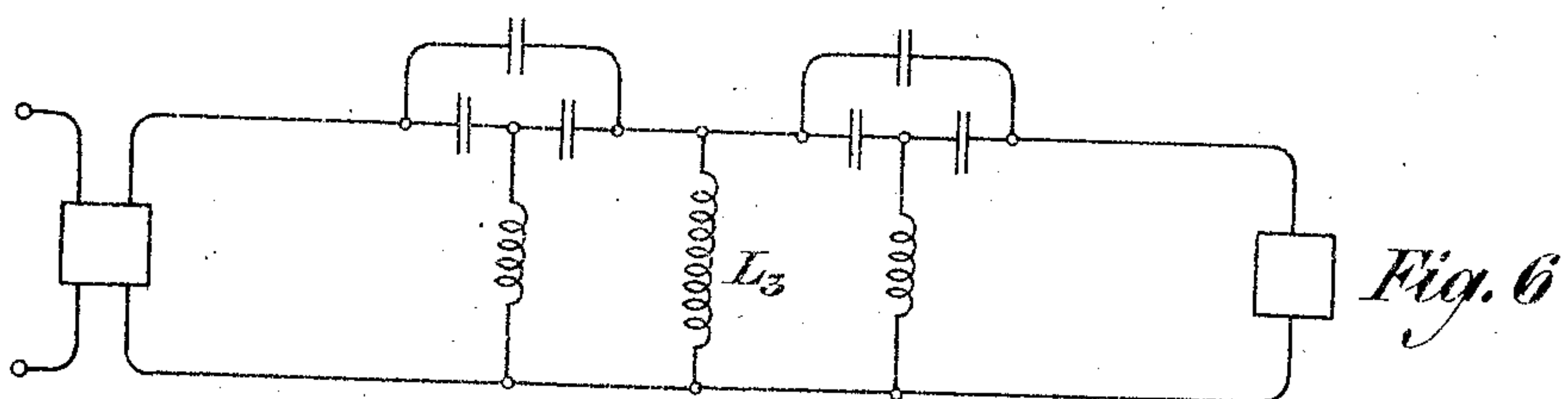
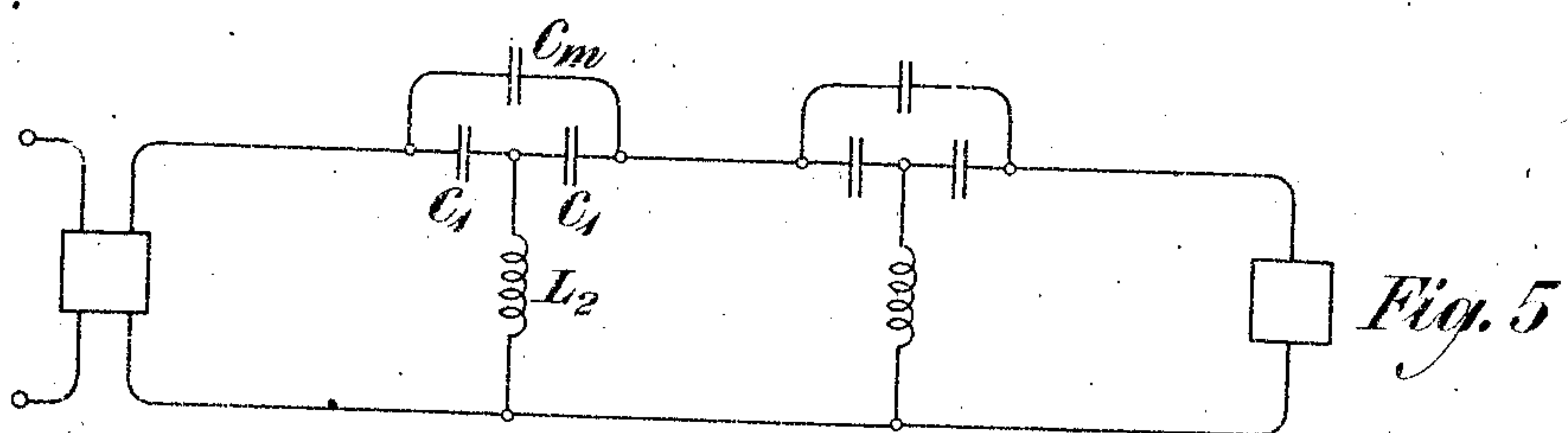
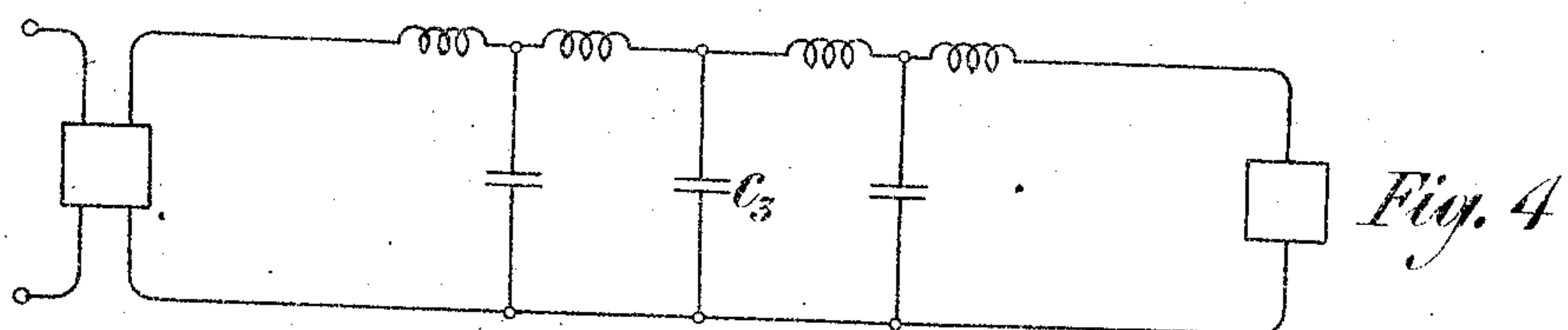
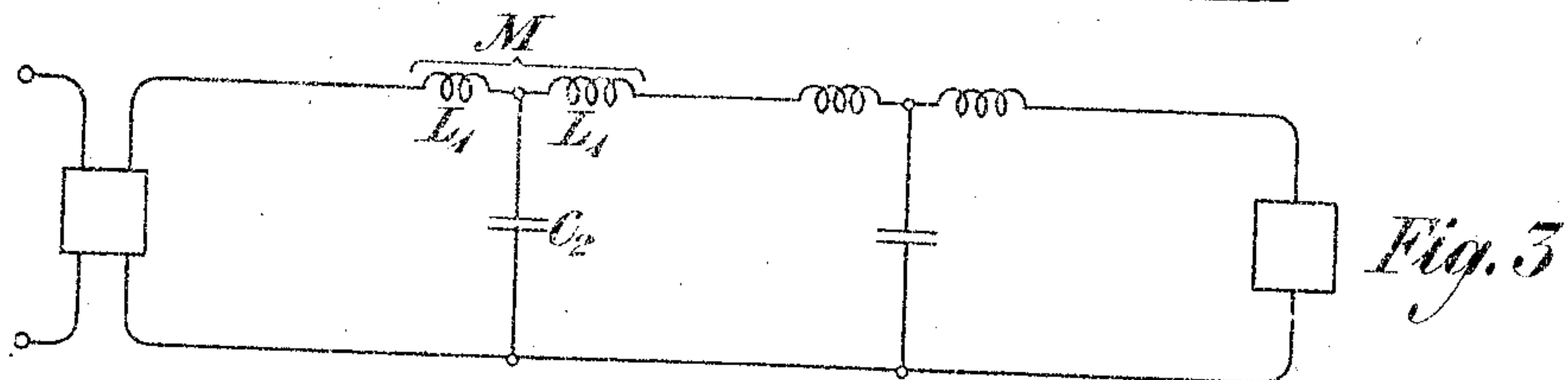
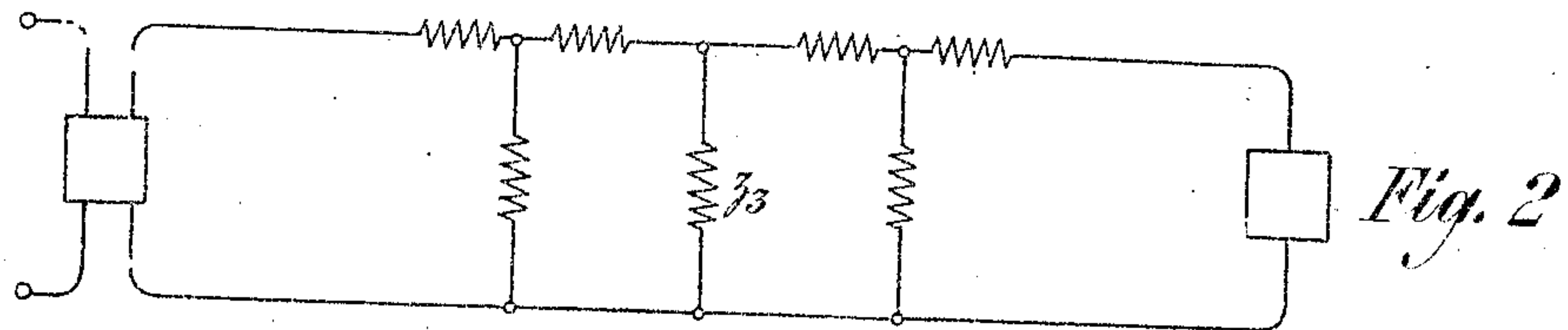
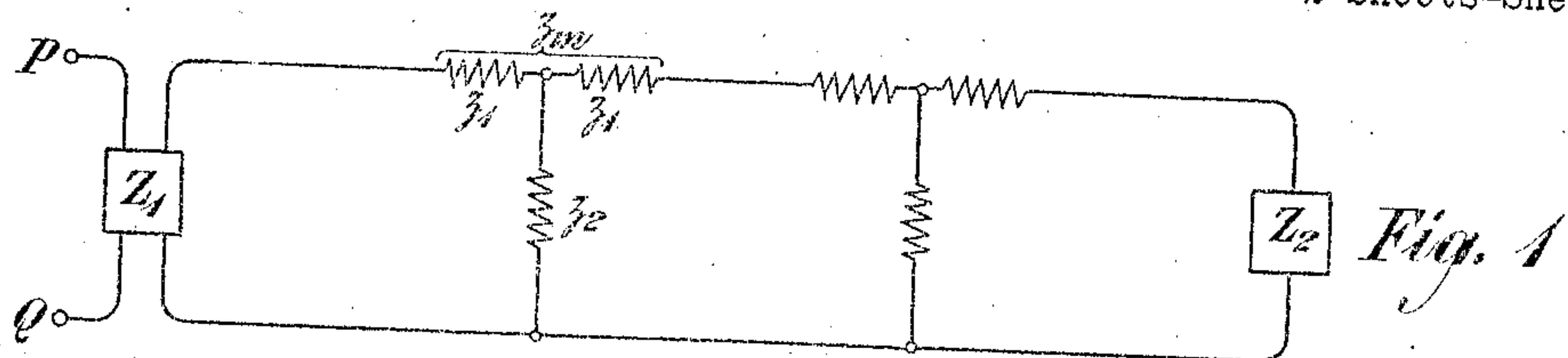
M. K. ZINN

1,632,814

FILTER FOR PERIODIC ELECTRIC CURRENTS

Filed Dec. 15, 1922

2 Sheets-Sheet 1



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FILTER FOR PERIODIC ELECTRIC CURRENTS

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2 Sheets-Sheet 2

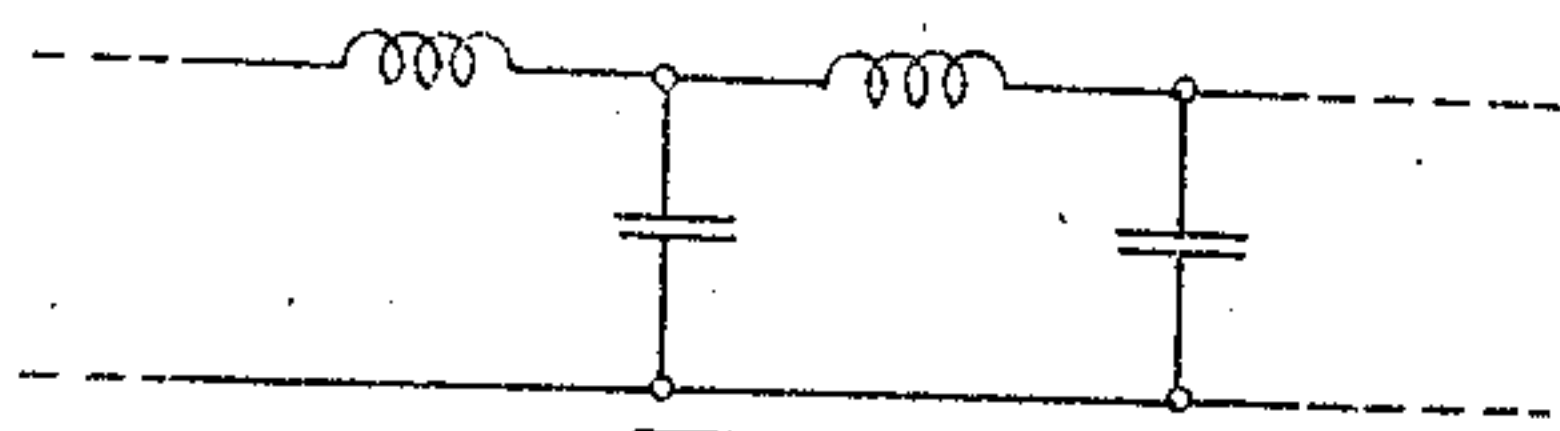


Fig. 11

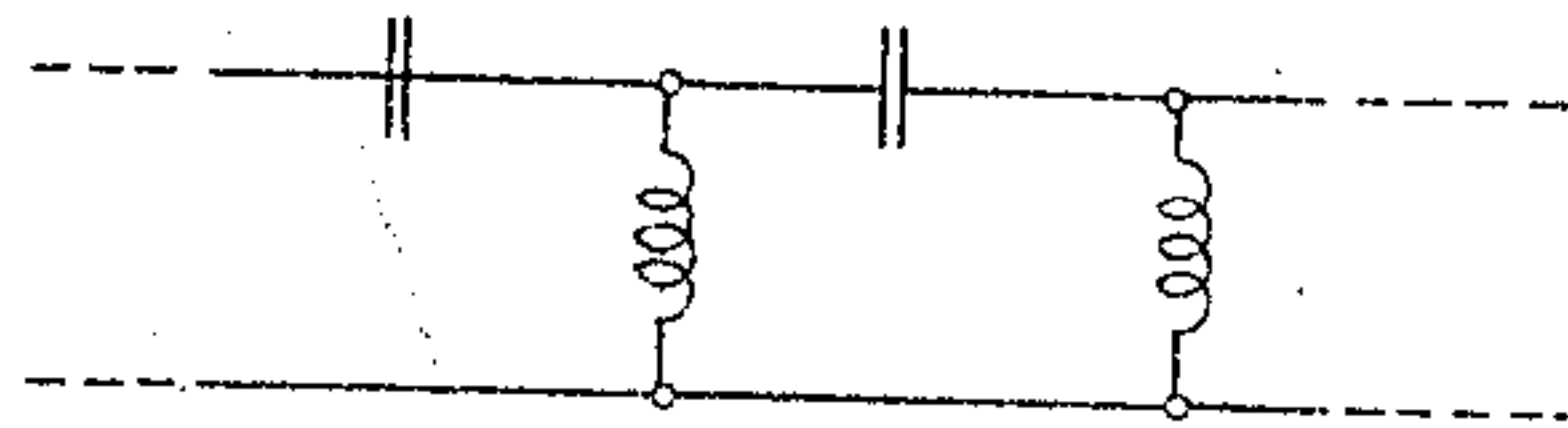


Fig. 12

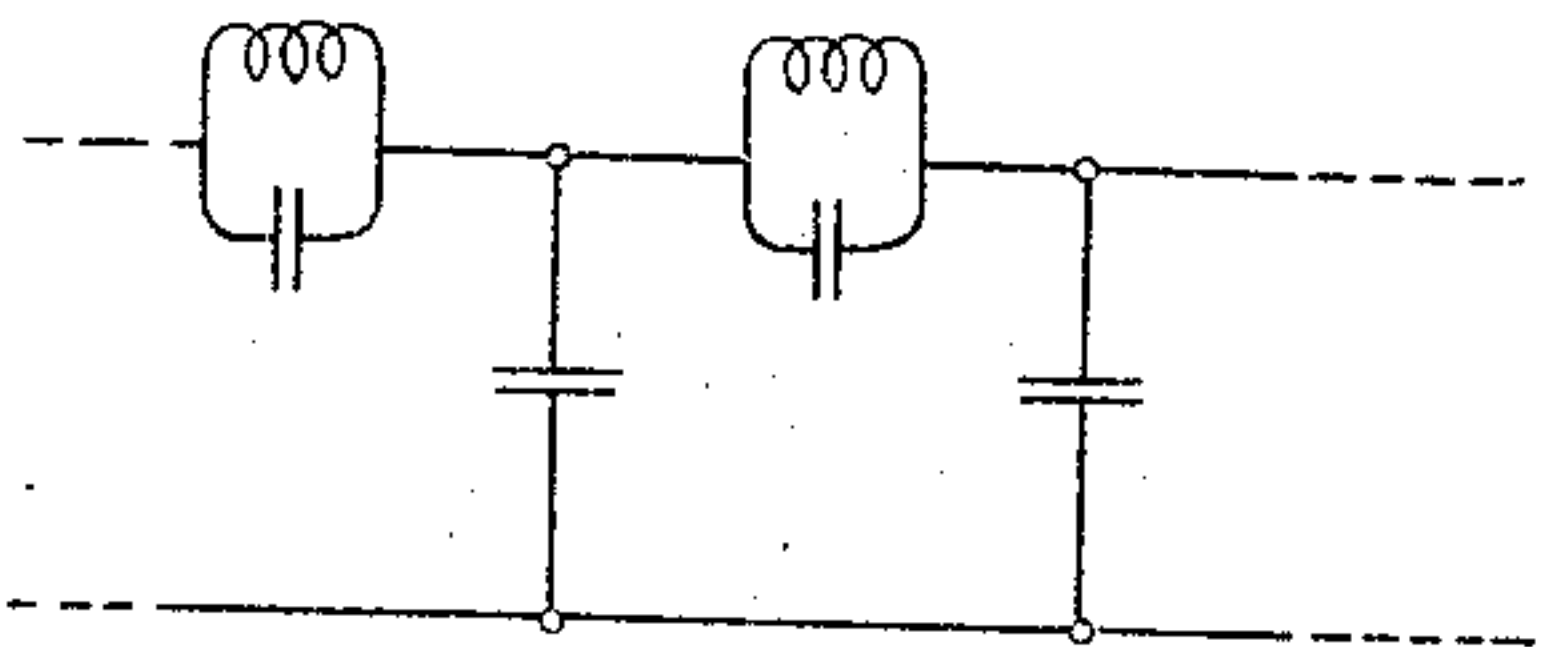


Fig. 13

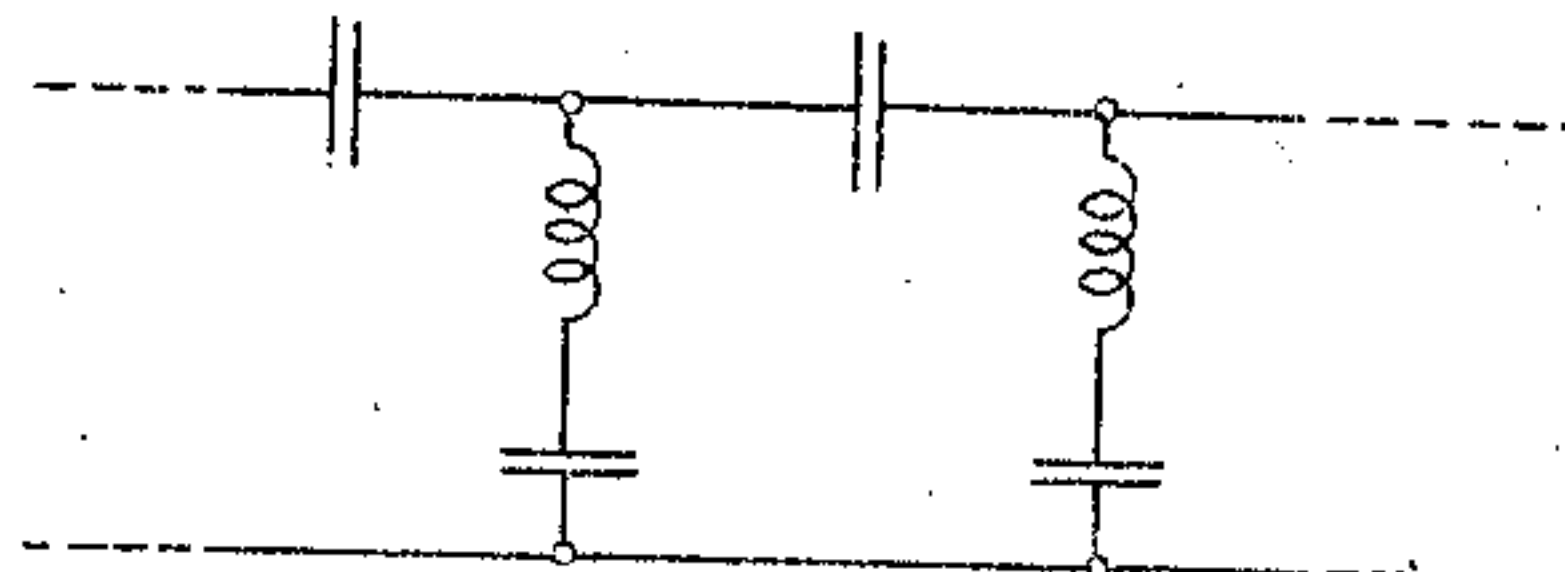


Fig. 14

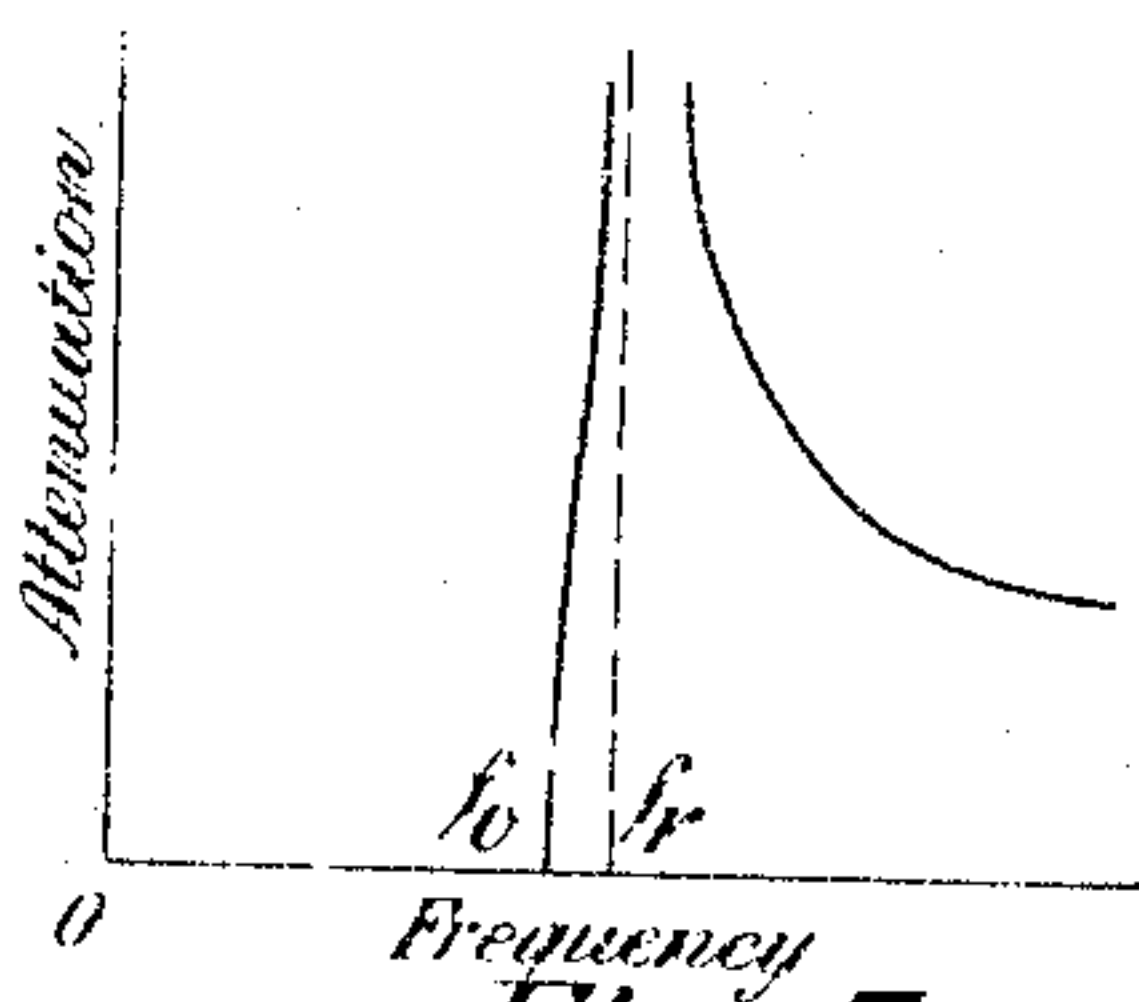


Fig. 7

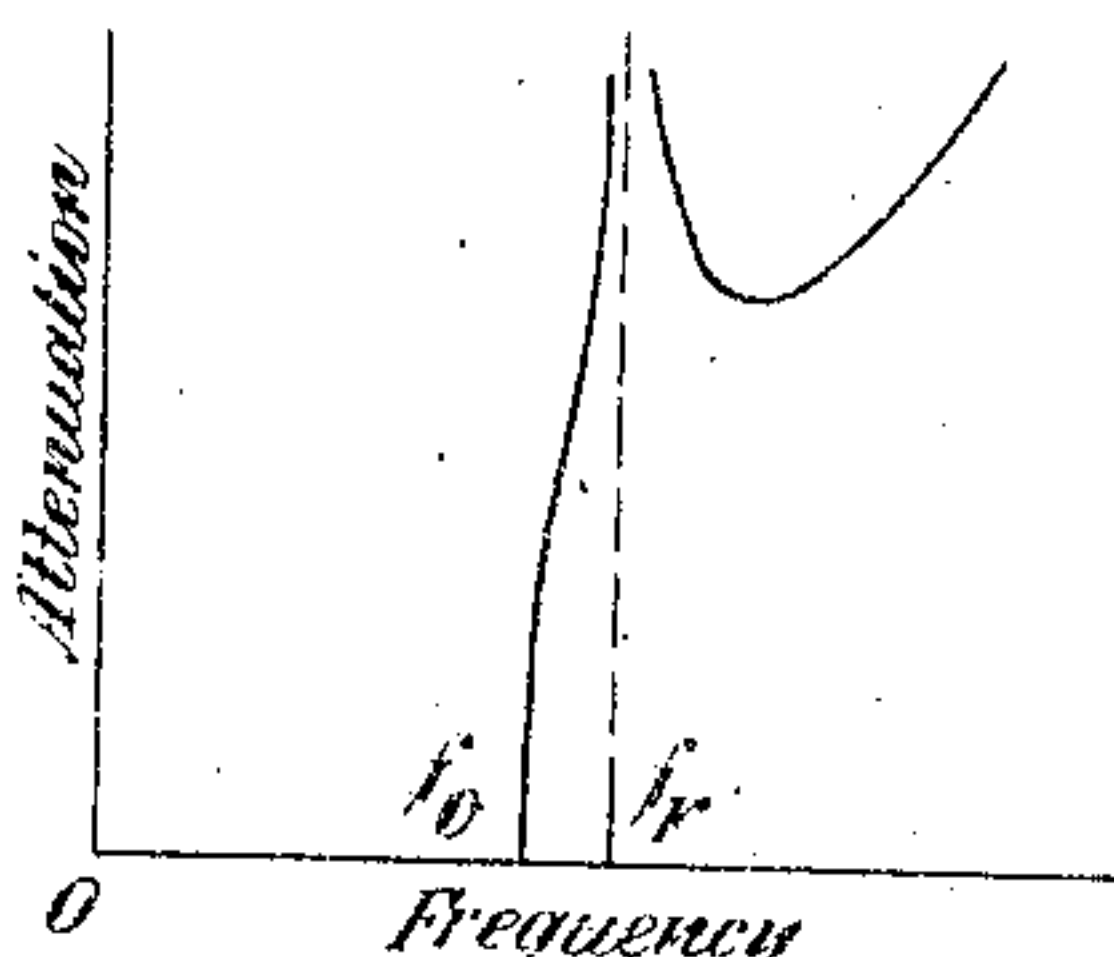


Fig. 8

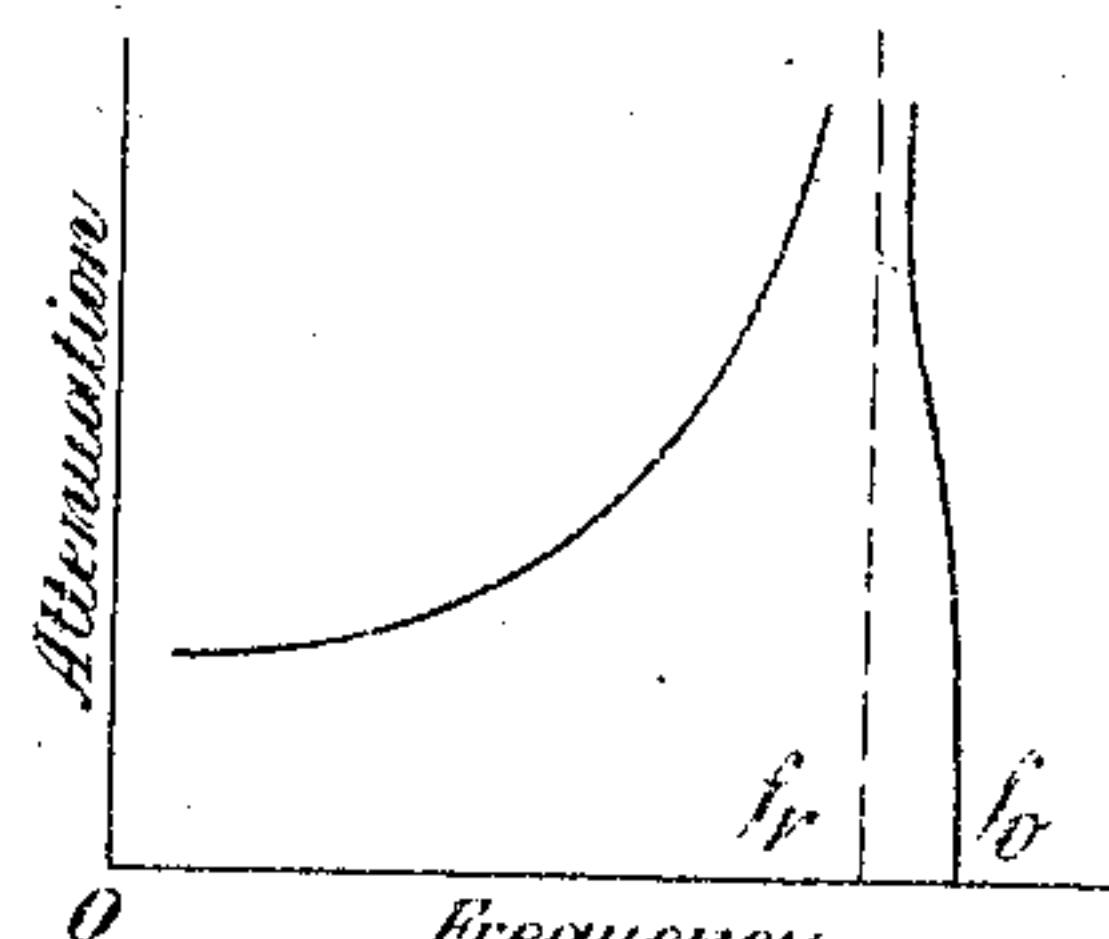


Fig. 9

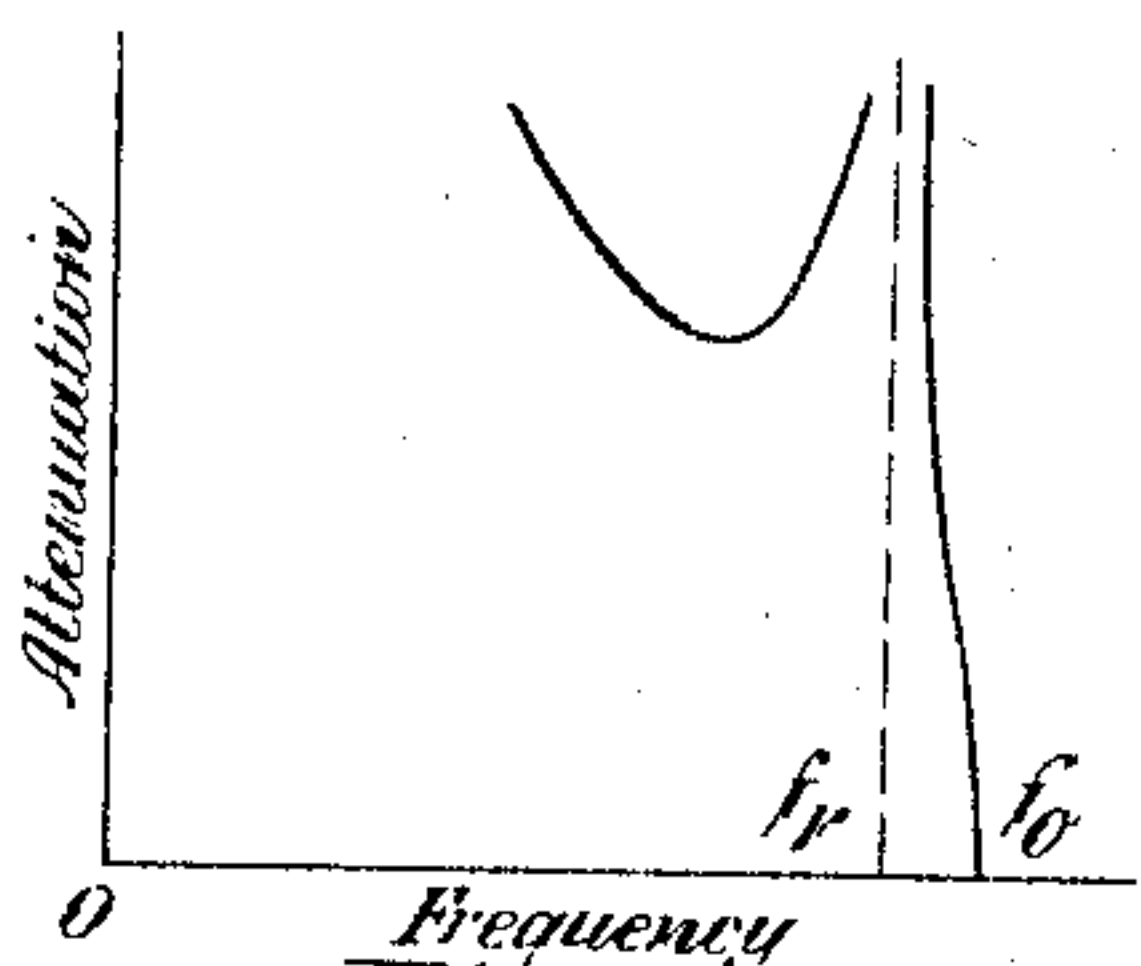


Fig. 10

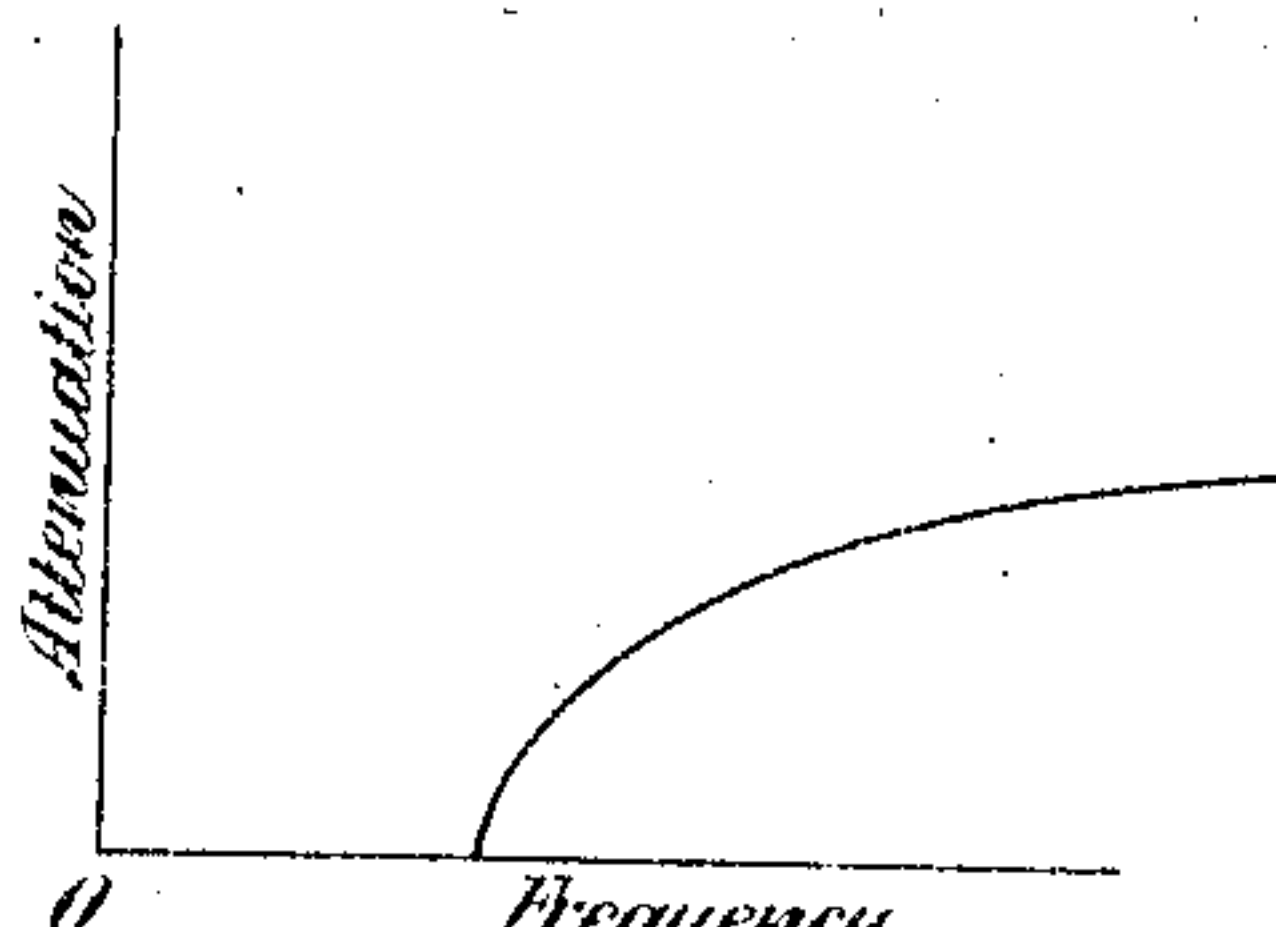


Fig. 15

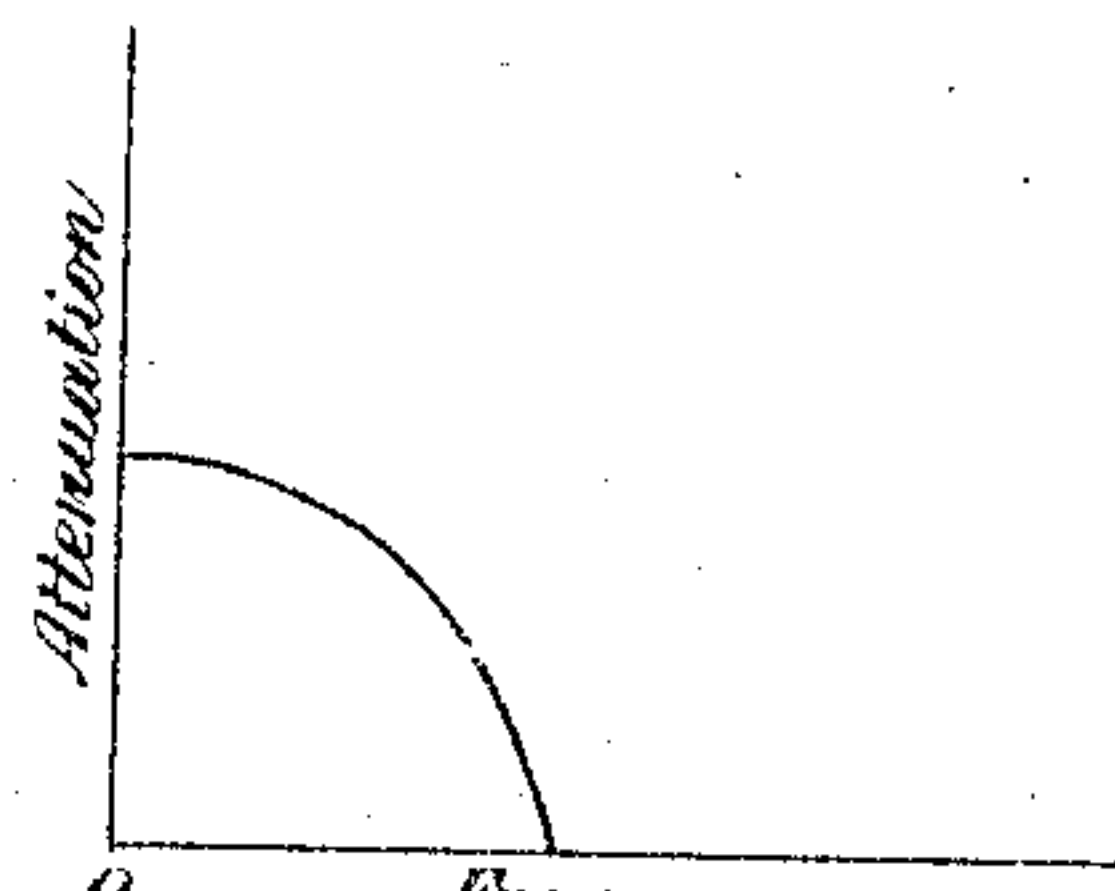


Fig. 16

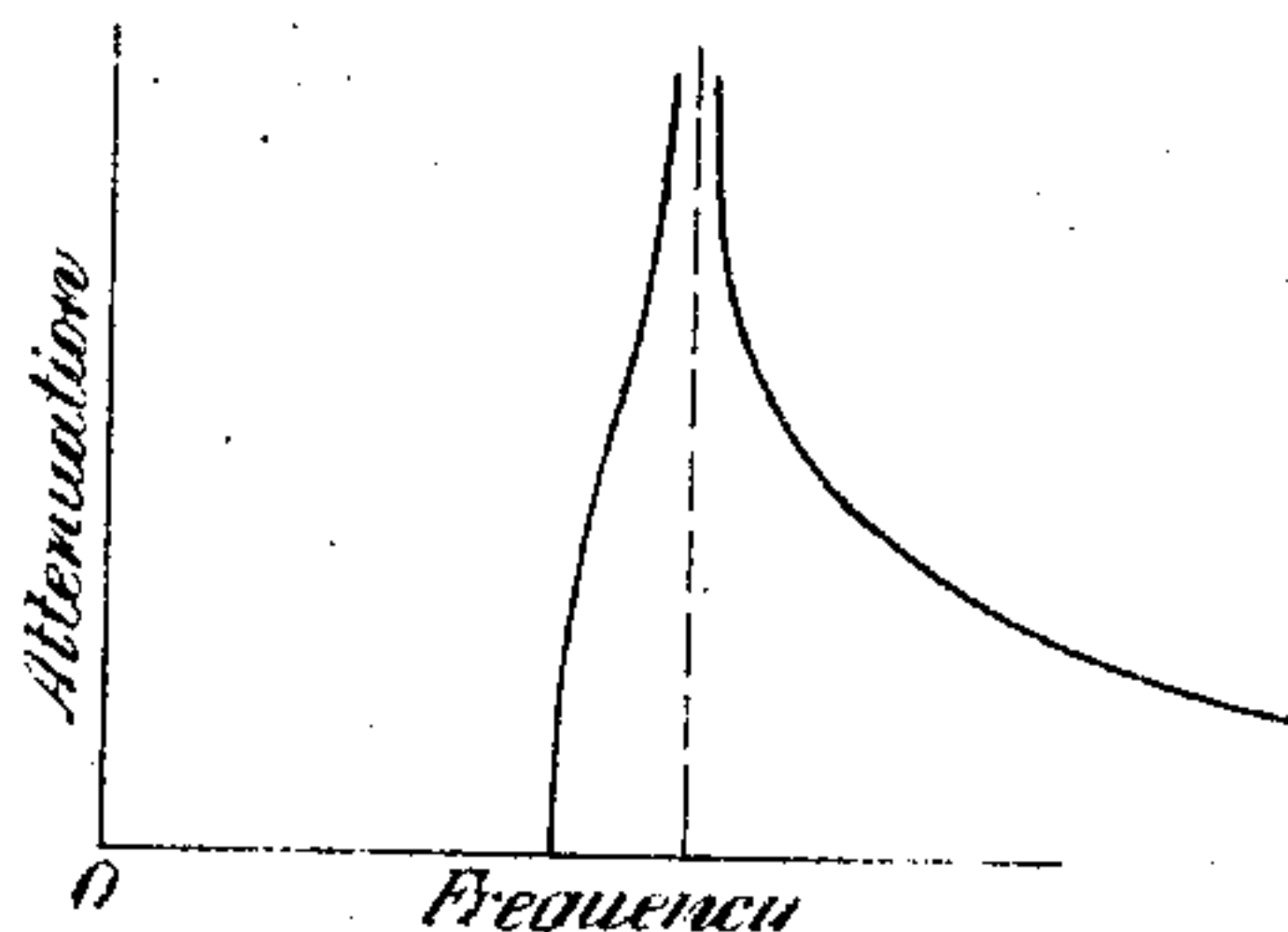


Fig. 17

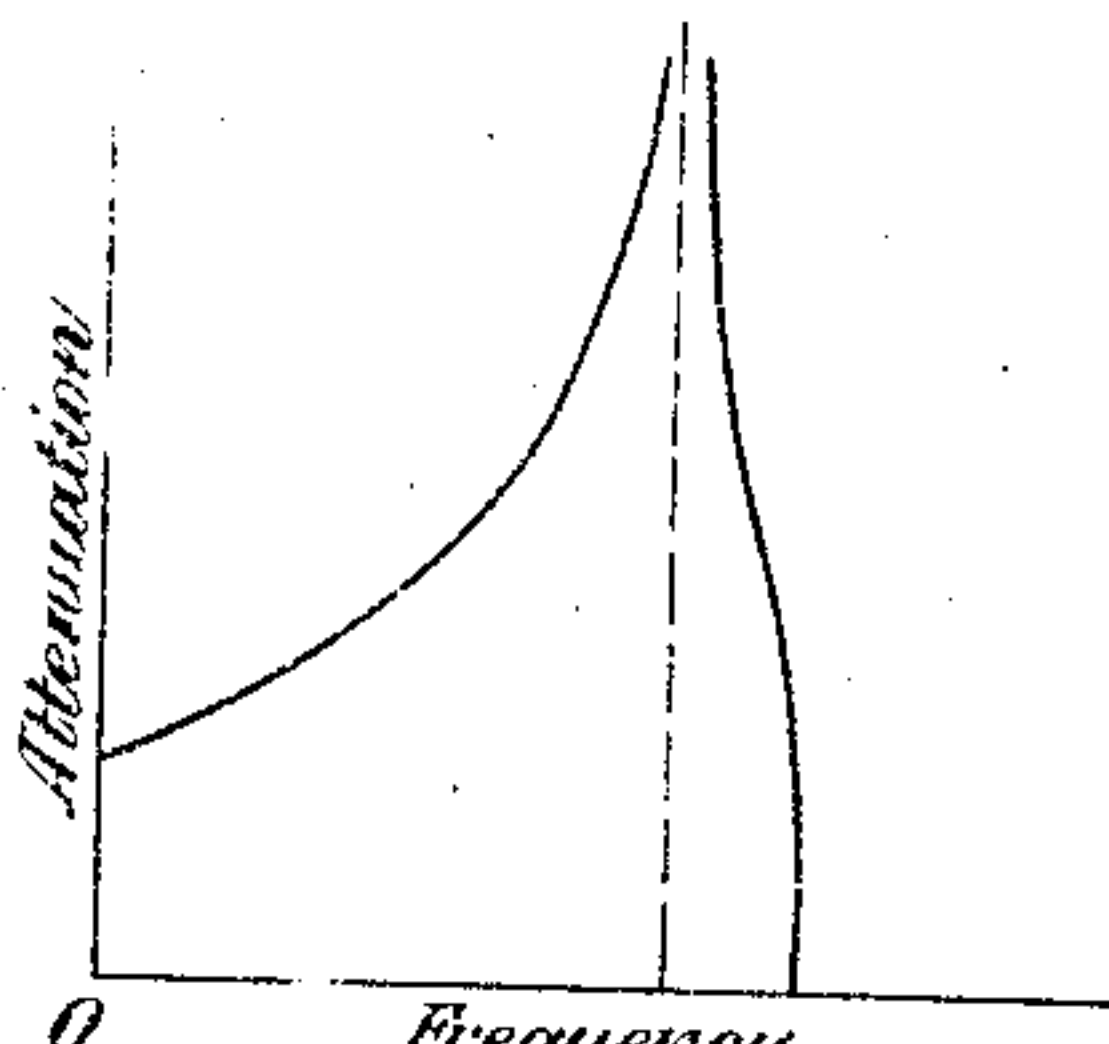


Fig. 18

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UNITED STATES PATENT OFFICE.

MANVEL K. ZINN, OF BROOKLYN, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

FILTER FOR PERIODIC ELECTRIC CURRENTS.

Application filed December 15, 1922. Serial No. 807,182.

An object of my invention is to provide a new and improved electric current filter of the type having recurrent sections. Another object of my invention is to provide such a filter having an advantageous attenuation characteristic and of simple and practicable structure. Another object is with simple structure to provide a filter with a sharp cut-off between the attenuated and transmitted zones of frequency. A further object is to do this with sustained high attenuation throughout the attenuated zone. Another object is to reduce the attenuation losses to a negligible amount within the transmitted zone of frequencies. All these and other objects of my invention will be made apparent in the following specification and claims, taken with the accompanying drawings, wherein I have disclosed a limited number of specific embodiments of the invention by way of illustration and example. It will be understood that the invention is defined in the appended claims.

Referring to the drawings, Figure 1 is a general diagram of a filter having mutual impedance between certain series elements. Fig. 2 is a filter like Fig. 1, with the interposition of additional shunt elements. Fig. 3 is a special case of Fig. 1, in which the impedance elements are shown as coils and condensers. Fig. 4 is a special case of Fig. 2, with the same qualification. Fig. 5 is another special case of Fig. 1. Fig. 6 is a corresponding special case of Fig. 2. Figs. 7, 8, 9 and 10 are characteristic diagrams for Figs. 3, 4, 5 and 6, respectively, showing attenuation as a function of frequency. Figs. 11, 12, 13 and 14 are diagrams of filters that will be referred to for purposes of comparison, and Figs. 15, 16, 17 and 18 are respective characteristics for these filters.

The properties of an electric wave filter are most easily demonstrated by first assuming that the structure consists of an infinite number of sections, and that the coils and condensers have no power losses. The performance of an actual filter will depart from this ideal case by a small amount depending upon the number of sections employed, the design of the terminal impedances, and the efficiency of the circuit elements.

In an artificial line comprising a very large number of identical sections the current decreases exponentially from one section to the next, that is:

$$\frac{J_N}{J_{N+1}} = e^{\gamma}$$

if N increases in the direction of propagation. The performance of the filter is therefore completely determined by Γ , the propagation constant per section.

The formulæ given in the following assume the ideal case of an infinite number of sections and no power losses.

For the filter shown in Fig. 3, whose attenuation characteristic is sketched in Fig. 7, the propagation constant per section is defined by

$$\cosh \Gamma = \frac{1 - p^2 L_1 C_2}{1 - p^2 M C_2}$$

where $p = 2\pi f$.

This expression shows that there is a range of free transmission from 0 to f_0 , where

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{2}{C_2(L_1 + M)}}$$

Frequencies higher than f_0 will be suppressed in varying degrees, the attenuation becoming infinite at a frequency

$$f_r = \frac{1}{2\pi \sqrt{M C_2}}$$

As the frequency is increased above f_r , the attenuation decreases, approaching a constant value,

$$\cosh -1 \frac{L_1}{M}$$

at very high frequencies. The ratio $\frac{f_r}{f_0}$, which is a measure of the discrimination, is a function of the coefficient of coupling,

$$k = \frac{M}{L}$$

viz:

$$\frac{f_r}{f_0} = \sqrt{\frac{1+k}{2k}}$$

The discrimination becomes sharper as k approaches 1, but the attenuation falls off more rapidly beyond f_r and approaches a lower final value.

To get the same selective characteristic without mutual inductance would require three impedance elements per section as for example in Fig. 13, whereas the filter shown in Fig. 1 has structurally only two elements per section, that is the pair of coils adjoining a bridging point would in practice consist of a single coil with a tap at its midpoint.

There is no difficulty in building toroidal coils having coefficients of coupling of 99 per cent, or greater between their two halves, so that the discrimination may be made as high as desired.

The structural difference between a simple low-pass filter with only two elements per section, as in Fig. 11, and the circuit

discussed above consists merely in the fact that the coils have been moved half a section so that they straddle the bridging points. The cut-off frequency of the new circuit differs from that of the simple filter having the same sized elements by the factor,

$$\sqrt{\frac{2}{1+k}}$$

The filter of Fig. 4 may be designed to give the attenuation characteristic of Fig. 8. It differs from Fig. 3 only in the addition of the extra capacity C_3 . This structure may be considered as a singly periodic structure by defining a section as the circuits included between two of the bridged capacities C_3 ; that is, the unit section is terminated at either end in one-half C_3 .

With the unit section so specified,

$$\cosh \Gamma = \frac{p^4 \left[C_2 C_3 \frac{L_1^2 - M^2}{2} \right] - p^2 [L_1 (C_2 + C_3) - M C_3] + 1}{1 - p^2 M C_2}$$

This filter will, in general, have two ranges of free transmission. Zero is one of the border frequencies and the others are:

$$f_1 = \frac{1}{2\pi} \sqrt{\frac{2}{C_2 (L_1 + M)}}$$

$$f_2 = \frac{1}{2\pi} \sqrt{\frac{2}{C_3 (L_1 + M)}}$$

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{2(C_2 + C_3)}{C_2 C_3 (L_1 + M)}}$$

There is also a frequency of infinite attenuation, viz:

$$f_r = \frac{1}{2\pi} \frac{1}{\sqrt{M C_2}}$$

The circuit constants may be so proportioned as to give a great variety of selective characteristics, and f_r may be made to fall within either of the opaque bands. If the network is intended to function as a low-pass filter, however, the characteristic of greatest importance is that shown in Fig. 8 where

$$f_1 = f_2 < f_0 < f_r$$

The two free ranges are merged into one by making $f_1 = f_2$, which occurs if

$$\frac{C_2}{C_3} = \frac{1-k}{1+k}$$

As the frequency increases from f_r to infinity, the attenuation first decreases from infinity to a certain minimum and then rises

again, the network becoming completely opaque at very high frequencies.

This filter is therefore capable of very sharp discrimination and at the same time greatly attenuates currents whose frequencies are remote from the transmitted band of frequencies.

The high-pass filters in Figs. 5 and 6 have attenuation characteristics corresponding exactly to those of Figs. 3 and 4. They differ only in being reversed. The high-pass characteristics are sketched in Figs. 9 and 10.

For the high-pass filter of Fig. 5 it can be shown that

$$\cosh \Gamma = \frac{2C_1(1 - p^2 L_2 C_1) - p^2 L_2 C_1 C_M}{C_M(1 - p^2 L_2 C_1) - p^2 L_2 C_1 C_M}$$

The frequency of cut-off is

$$f_0 = \frac{1}{2\pi \sqrt{2L_2 C_1}}$$

and the frequency of maximum attenuation is

$$f_r = \frac{1}{2\pi \sqrt{L_2 C_1 \left(\frac{C_1}{C_M} + 2 \right)}}$$

The discrimination is given by

$$\frac{f_0}{f_r} = \sqrt{\frac{C_1}{2C_M} + 1}$$

The filter of Fig. 6 has, in general, a propagation constant per section defined by

$$\cosh \Gamma = \frac{p^4 2L_2 L_3 C_1 (C_1 + 2C_M) - p^2 2(L_2 (C_1 + C_M) + L_3 C_1) + 1}{p^4 2L_2 L_3 C_1 (C_1 + 2C_M) - p^2 2L_3 C_M}$$

It will function as a high-class filter if the elements are so proportioned that

$$\frac{L_2}{L_1} = \frac{C_1 + 2C_M}{C_1}$$

For this design the frequency of cut-off is

$$f_c = \frac{1}{4\pi \sqrt{L_2 C_1 \frac{C_1 + C_M}{C_1 + 2C_M}}}$$

and the frequency of maximum attenuation is

$$f_r = \frac{1}{2\pi \sqrt{L_2 C_1 (C_1 + 2C_M)}}$$

The discrimination is given by

$$\frac{f_o}{f_r} = \frac{C_1 + 2C_M}{2\sqrt{C_M(C_1 + C_M)}}$$

This filter is capable of sharp discrimination while at the same time greatly attenuating currents of low frequencies remote from the free range.

Both of the high-pass filters in Figs. 5 and 6 have the advantage that the total inductance and capacity required per section is less than that required for the ordinary 3-element filter without mutual impedance and having the same characteristic as regards cut-off point and discrimination. Such a 3-element filter is shown for example in Fig. 14. The resistance dissipation is, therefore, less, which gives a higher attenuation in the suppressed region, particularly at the frequency of maximum attenuation. The loss in the transmitted range is also smaller for the same reason.

In the practical application of wave filters a knowledge of their impedance characteristics is required. Expressions for the impedance of the filters heretofore described will now be given. It is found that the impedance of these filters varies with the frequency in exactly the same manner as does the impedance of simple 2-element or 3-element high and low pass filters. In fact the impedance may be made to coincide with the impedance characteristics of the ordinary types of filters, which makes it practicable to use these filters in conjunction with the other types.

Only one termination of these filters will be considered, namely, at a point between two of the T network structures. When the extra impedance Z_3 has been added as in Fig. 4 and Fig. 6, the filter will be considered terminated in $Z_2 = 2Z_3$. Other terminations might be devised which would improve the impedance characteristics as has been done for the ordinary types of filters.

The impedance of the filter of Fig. 3 when terminated as defined above is:

$$Z = \sqrt{\frac{2(L_1 - M)}{C_2} - p^2(L_1 - M)(L_1 + M)}$$

or in terms of

$$k \left(= \frac{M}{L_1} \right)$$

$$Z = \sqrt{\frac{2L_1}{C_2}(1 - k) - p^2 L_1^2 (1 - k^2)}$$

The impedance is a pure resistance in the free range approaching a value

$$Z(o) = \sqrt{\frac{2(L_1 - M)}{C_2}} = \sqrt{\frac{2L_1}{C_2}(1 - k)}$$

at zero frequency. It becomes zero at the cut-off point and is a pure inductive reactance in the suppressed range. In particular, at the frequency of maximum attenuation it is

$$Z(p_r) = j(1 - k) \sqrt{\frac{L_1}{kC_2}}$$

From the above description it will be recognized that this filter has the same impedance characteristic as either a simple or 3-element filter with mid-series termination. It can be made to have exactly the same impedance at all frequencies as the simple filter having the same cut-off point by designing it so that

$$L_1 = \frac{L}{2\sqrt{1 - k^2}} \text{ and } C_2 = C \sqrt{\frac{1 - k}{1 + k}}$$

if L and C are the elements of the simple filter k . The discrimination is left free to choice.

The filter of Fig. 4 is terminated in $\frac{C_3}{2}$ and has the same impedance characteristic as the midshunt impedance of a simple or 3-element filter.

The impedance at any frequency is given by

$$Z = \sqrt{\frac{L_1(1 - k)^2}{C^2(4 - p^2 C_2 L_1(1 + k)^2)}}$$

This applies to the design where $p_1 = p_2$. As stated above this is brought about by making

$$\frac{C_2}{C_3} = \frac{1 - k}{1 + k}$$

The impedance approaches a constant value at zero frequency, viz:

$$Z(o) = \frac{1 - k}{2} \sqrt{\frac{L_1}{C_2}}$$

It is a pure resistance in the free range, becoming infinite at the cut-off point, p_o . In the suppressed range beyond p_o it is a pure

inductive reactance, falling to zero at very high frequencies.

Other values of interest are:

$$Z(p_1 - p_2) = \sqrt{\frac{L_1(1-k)}{2C_2}} = \sqrt{\frac{L_1 - M}{2C_2}} = Z(o) \sqrt{\frac{2}{1-k}}$$

$$Z(p_r) = j\sqrt{\frac{L_1 k}{C_2}} = j\sqrt{\frac{M}{C_2}}$$

The impedance of the structure of Fig. 5 is given by

$$Z = \sqrt{\frac{1 - 2p^2 L_2 C_1}{-p^2 C_1 (2C_M + C_1)}}$$

Like the corresponding low pass filter of Fig. 3, the impedance is a resistance in the free range and a positive reactance in the suppressed range and passes through zero at the point of cut-off.

At very high frequencies

$$Z \text{ approaches } \sqrt{\frac{2L_2}{C_1 + 2C_M}}$$

Z is infinite at zero frequency.

$$Z = \sqrt{\frac{4p^2 L_2^2 C_1^2}{(C_1 + 2C_M) [4p^2 L_2 C_1 (C_1 + C_M) - (C_1 + 2C_M)]}}$$

The impedance characteristic is similar to that of the high pass simple or 3-element filter when terminated at mid-shunt. That is, Z is a resistance in the free range and a positive reactance in the suppressed range and has an infinite value at the cut-off point.

At zero frequency, the impedance is zero, and at very high frequencies it approaches the constant value.

$$Z(\infty) = \sqrt{\frac{L_2 C_1}{(C_1 + 2C_M)(C_1 + C_M)}}$$

I claim:

1. A filter having successive shunt impedance elements and series elements in alternation therewith, adjacent series elements having mutual impedance in pairs.

2. A filter having successive shunt reactance elements of the same algebraic sign and alternately arranged series reactance elements of opposite sign, said series elements having mutual reactance in pairs.

3. A filter having series impedance elements and shunt impedance elements arranged successively in alternation, the shunt elements being alternately of two values and the series elements having mutual impedance around the shunt elements of one value, but not the other.

Another convenient point for computation is

$$Z(p_r) = j\sqrt{\frac{L_2 C_1}{C_M(C_1 + 2C_M)}}$$

This filter may be made to have the same impedance as the mid-series impedance of either the simple or 3-element high pass filter by proper proportionment of the circuit constants.

As pointed out before, the design of particular importance for the filter of Fig. 6 is fixed by the relation,

$$\frac{L_2}{L_1} = \frac{C_1 + 2C_M}{C_1}$$

The structure is considered terminated in $2L_2$. With this termination

4. A filter having successive shunt impedance elements and alternately arranged series elements, said series elements having mutual impedance connection in pairs, whereby the combination gives a sharp cut-off between the transmitted and attenuated frequency ranges and a sustained attenuation within the attenuated range.

5. A filter having successive alternately disposed series and shunt impedance elements, the series elements having mutual impedance connections in adjacent pairs and the shunt elements having two different values, one value when they stand between series elements having mutual impedance connection and another value when they stand between impedance elements not so connected.

6. A filter having successive series impedances with mutual impedance connection between adjacent impedances in pairs and having shunt impedances respectively between the members of each series pair and having means to hold up the attenuation to a sustained high value throughout the entire attenuating range of the filter.

In testimony whereof, I have signed my name to this specification this 13th day of December, 1922.

MANVEL K. ZINN.