

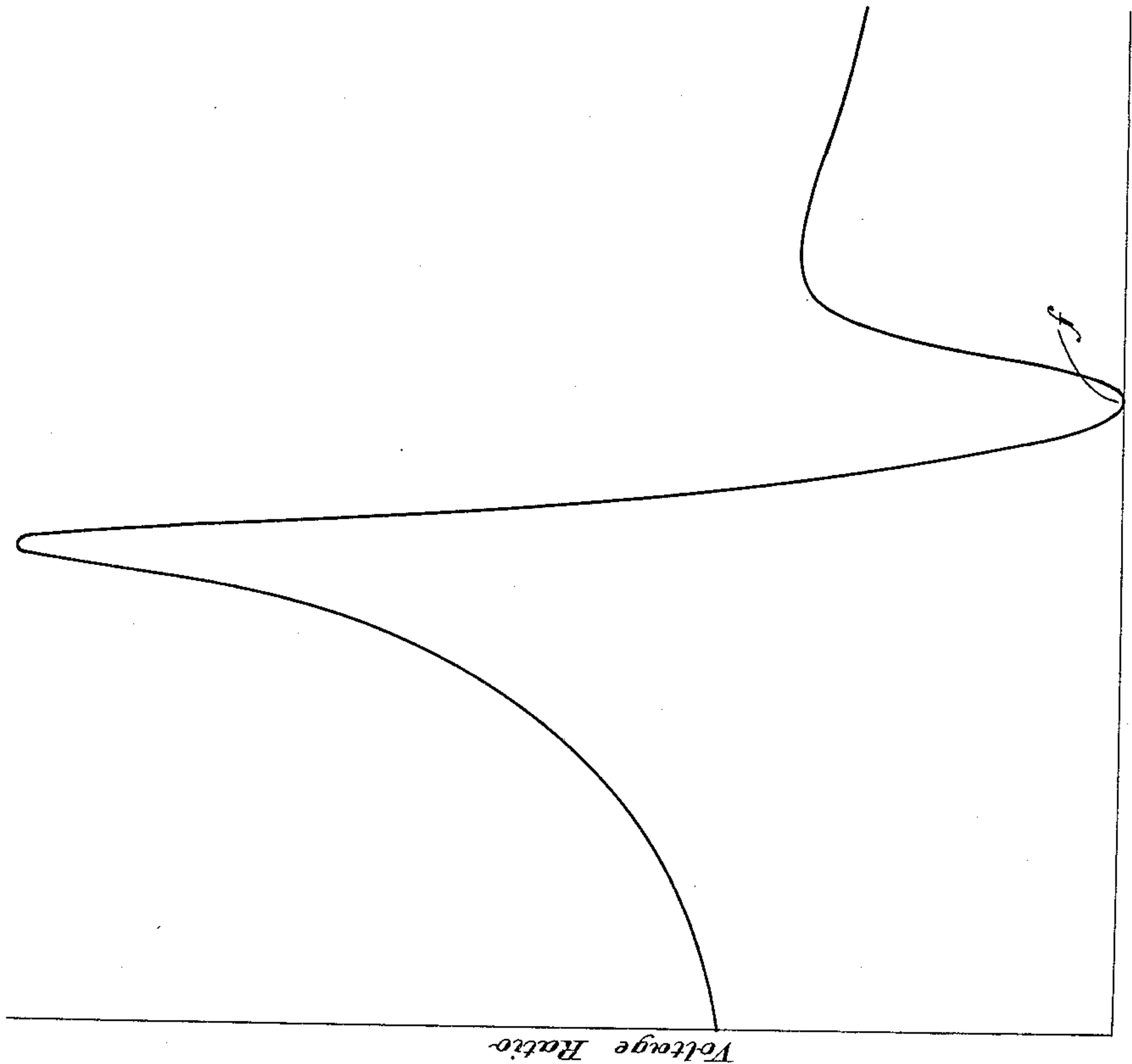
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1,848,221

FILTER ARRANGEMENT

Filed May 29, 1928



Frequency
Fig. 3

Windings L_1 , L_2 and L_3 exhibit resistances r_1 , r_2 , and r_3 , respectively.

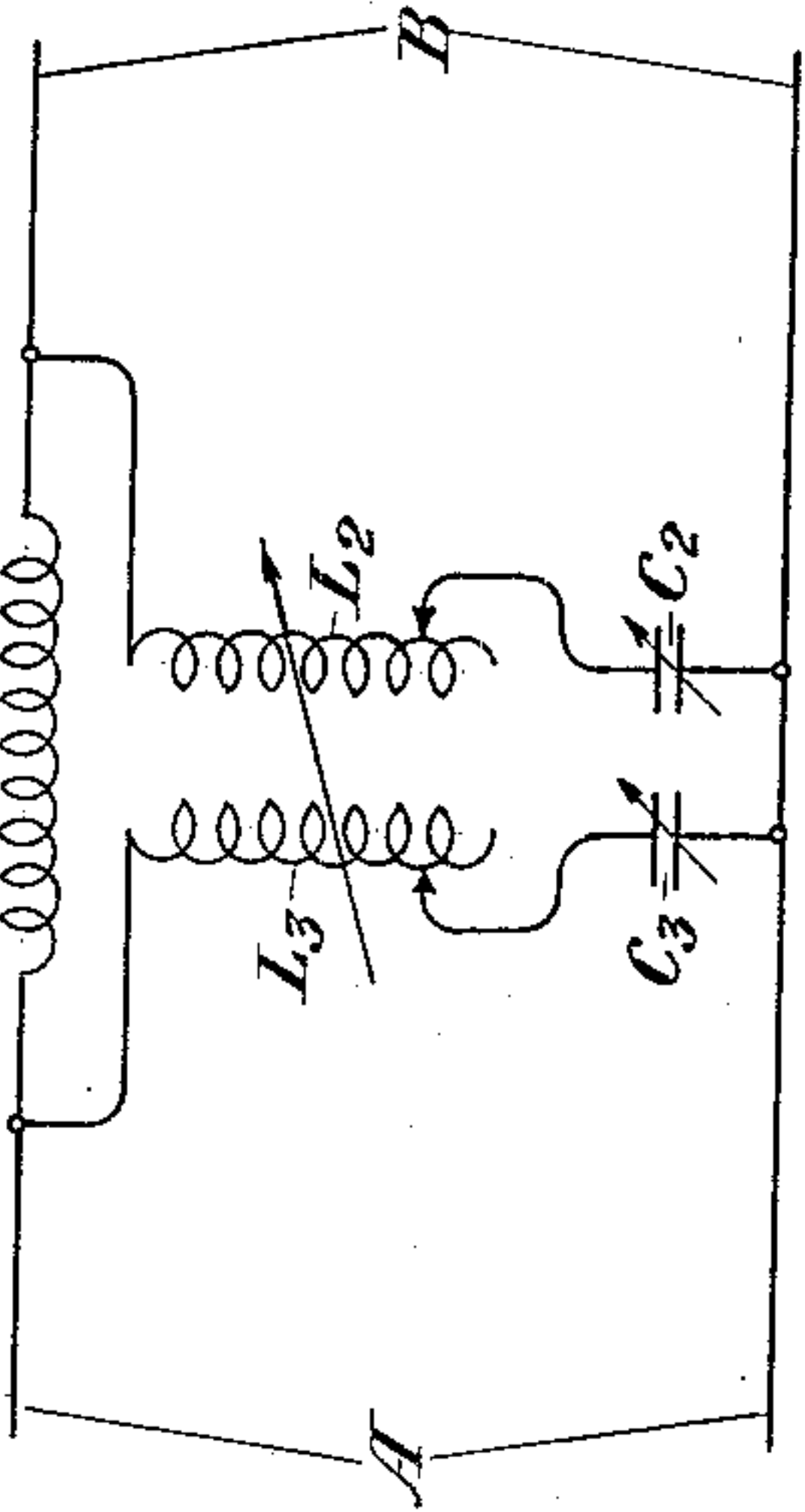


Fig. 1

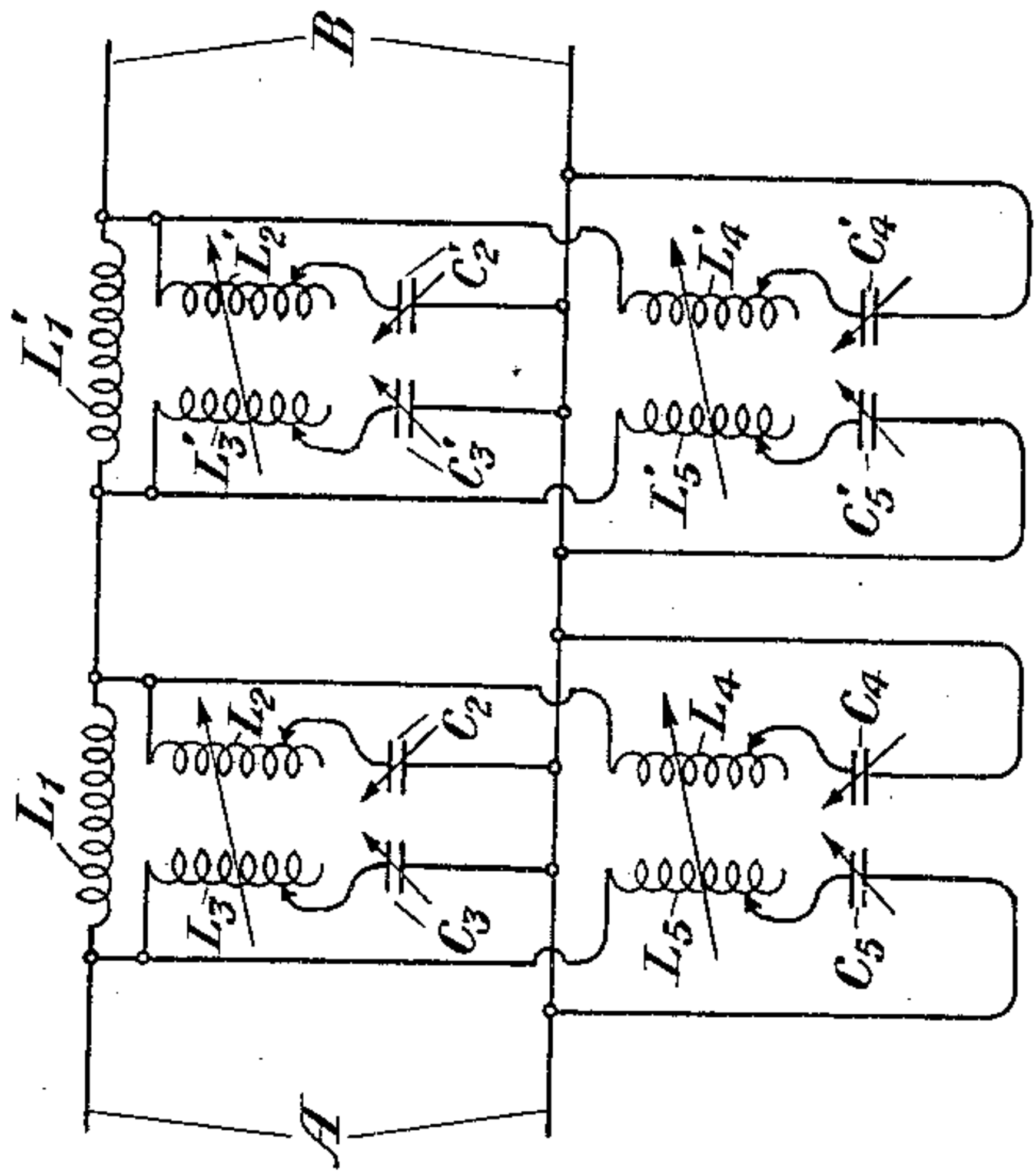


Fig. 2

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FILTER ARRANGEMENT

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This invention relates to electrical wave filters, and more particularly to wave filters adapted to attenuate and substantially suppress current of a particular frequency or currents of frequencies lying within the limits of a predetermined band or range.

This invention, though it may find expression in many embodiments, has common to all the broad idea of a wave filter in the nature of a network interconnecting an input circuit and an output circuit, in which an inductive element, or reactor, is located in series between said input and output circuits, and series circuits including inductive and capacitative reactances are located in shunt across said input and output circuits, the series and shunt elements being so proportioned that the network will suppress sinusoidal current of a particular frequency, or sinusoidal currents within a specified and predetermined band or range flowing from the input circuits.

This invention has important applications in systems for rectifying alternating current, and particularly in such systems employing rectifiers which produce a plurality of harmonic frequencies of the current supplied thereto, these harmonics interfering with the quality of speech which may be transmitted over an exposed telephone circuit. By means of the network comprising the filter of this invention, one or more of these harmonic frequencies produced by the rectifier, or rectifiers, may be substantially suppressed and eliminated, while the direct current may be freely transmitted.

This invention is illustrated in the accompanying drawings, in which Figure 1 represents a diagram illustrating the broad form of the invention from which specific embodiments may be derived; Fig. 2 illustrates a modification of the arrangement shown in Fig. 1 and employing a plurality of recurrent sections, and Fig. 3 shows a curve illus-

trating the characteristic performance of the wave filter of this invention.

Referring to Fig. 1, there is shown a filter inter-connecting an input circuit A and an output circuit B. This filter consists of one series inductance, i. e., a series coil L_1 , and two shunt branches each composed of an inductance and a capacity in series relationship, windings L_2 and L_3 and condensers C_2 and C_3 , respectively, representing these shunt branches. Coils L_2 and L_3 are coupled together and arranged so that there is mutual inductance therebetween. Coils L_1 , L_2 and L_3 may be considered to exhibit resistances which may be designated r_1 , r_2 and r_3 , respectively. It will be apparent that resistance elements may be definitely connected in series with coils L_1 , L_2 and L_3 which may be adjustable so that any magnitude of resistance may be interposed in series in each of these three circuits.

If the branch including winding L_2 and condenser C_2 which shunts the output circuit B be tuned by adjusting the magnitude of the inductance of winding L_2 or of the capacity of condenser C_2 to resonance at a particular frequency intended for suppression, a substantial current I_2 of the frequency of resonance will flow through this shunt branch. Since r_2 designates the resistance in this shunt branch, the voltage E_B at the output circuit B at the tuned frequency will be $I_2 r_2$. The current I_2 in this shunt branch will lag behind the voltage E_A of the input circuit by an angle whose tangent is

$$\frac{L_1 \omega}{r_1 + r_2}$$

The branch including the winding L_3 and the condenser C_3 which shunts the input circuit A may be adjusted in its inductive or capacitative magnitudes, or by varying the coupling between its winding L_3 and the winding L_2 of the branch shunting the output

circuit B, so that a current I_3 of the same frequency to which the branch shunting the output circuit B is resonant will flow there-through and will lead the current I_2 by 90° .
 If M designates the coupling existing between windings L_2 and L_3 , then the voltage $MI_3\omega$ induced in the circuit including the winding L_2 will lead the current I_3 by 90° , and the current I_2 by 180° , and this voltage will therefore be 180° out of phase with respect to the voltage drop across the circuit including winding L_2 . It will be apparent that by suitably adjusting the coupling M between the windings L_2 and L_3 , the voltage produced across the circuit including winding L_2 and condenser C_2 , i. e., I_2r_2 , may be balanced out by a voltage of equal magnitude and of opposite polarity produced by the circuit including winding L_3 and condenser C_3 . Accordingly, the current of the resonant frequency will be negligible and ineffective in the output circuit B.

It may be readily shown that the voltage ratio of this network may be given by the expression

$$\frac{E_B}{E_A} = \frac{m^2 - mZ_1 - Z_2Z_3}{m^2 - Z_1Z_3 - Z_2Z_3} \quad (1)$$

where

$$m = jM\omega \quad (1a)$$

$$Z_1 = r_1 + jL_1\omega \quad (1b)$$

$$Z_2 = r_2 + j\left(L_2\omega - \frac{1}{C_2\omega}\right) = r_2 + jX_2 \quad (1c)$$

$$Z_3 = r_3 + j\left(L_3\omega - \frac{1}{C_3\omega}\right) = r_3 + jX_3 \quad (1d)$$

It will be apparent that the ratio E_B/E_A of Equation (1) will be zero if the numerator of the expression at the right-hand side of the sign of the equation is zero. Thus, the ratio E_B/E_A will be zero when

$$m^2 - mZ_1 - Z_2Z_3 = 0. \quad (2)$$

Substituting for m , Z_1 , Z_2 and Z_3 , the values determined by Expressions (1a), (1b), (1c) and (1d), it will be clear that the following expression will be true:

$$-M^2\omega^2 - jM\omega(r_1 + jL_1\omega) - (r_2 + jX_2)(r_3 + jX_3) = 0 \quad (2a)$$

By the process of expansion, Equation (2a) becomes

$$-M^2\omega^2 - jM\omega r_1 + ML_1\omega^2 - r_2r_3 - j r_2X_3 - jX_2r_3 + X_2X_3 = 0 \quad (2b)$$

Clearly, the real and imaginary components of Expression (2b) may be equated to zero, the real components giving the expression

$$-M^2\omega^2 + ML_1\omega^2 - r_2r_3 + X_2X_3 = 0 \quad (3)$$

and the imaginary components, the expression

$$-M\omega r_1 - r_2X_3 - X_2r_3 = 0 \quad (4)$$

Let the branch including winding L_2 and condenser C_2 be tuned to resonance at the frequency intended for suppression, then $L_2\omega = 1/C_2\omega$, and the reactance in this branch will be zero. At the frequency of resonance, since the reactance X_2 is zero, Equation (3) becomes

$$-M^2\omega^2 + ML_1\omega^2 - r_2r_3 = 0 \quad (5)$$

and Expression (4) becomes

$$-M\omega r_1 - r_2X_3 = 0 \quad (6)$$

Upon transposing the first and third terms of Expression (5), the value of L_1 may be determined.

$$L_1 = \frac{r_2r_3}{M\omega^2} + M \quad (6a)$$

And if the inductances of windings L_2 and L_3 be assumed to be equal, the coefficient of coupling k will have the following value:

$$k = M/\sqrt{L_2L_3} = M/L_2 \quad (6b)$$

$$\text{and } M = kL_2 \quad (6c)$$

If the value of M determined by Expression (6c) be substituted in Expression (6a), then

$$L_1 = \frac{r_2r_3}{kL_2\omega^2} + kL_2 \quad (7)$$

Upon inspection of Equation (7), it will be apparent that there is one value of k at which the inductance of winding L_1 will be a minimum. A low inductance for winding L_1 is particularly desirable because in power circuit rectifying systems a heavy current will flow over the main line and therefore through winding L_1 . A low inductance will have but a few turns, and its cost will not be prohibitive.

Upon differentiating Expression (7) with respect to k , and equating the result to zero, the following condition will hold:

$$\frac{-r_2r_3}{k^2L_2\omega^2} + L_2 = 0 \quad (7a)$$

Since windings L_2 and L_3 were assumed to have equal inductances, assume also their resistances r_2 and r_3 (or the resistances of the branches including these windings) to be equal, and Expression (7a) becomes

$$\frac{r_2^2}{k^2L_2\omega^2} = L_2 \quad (7b)$$

and

$$k^2 = \frac{r_2^2}{L_2^2\omega^2} \quad (8)$$

Then

$$k = \frac{r_2}{L_2\omega} = \frac{1}{Q_2} \quad (8a)$$

in which Q_2 represents the ratio of reactance to resistance, or $\omega L_2/r_2$.

Equation (8a) shows that the inductance of coil L_1 will be a minimum when the coefficient of coupling is $1/Q_2$. A value as low as 5 may be conveniently assigned to Q_2 in practice. Then k will be 0.2, a coupling which may be easily attainable with air core coils. Also, the shunt branches including windings L_2 and L_3 may be made up of small compact coils since a large value for Q_2 is not necessary, and consequently their cost will be comparatively small.

Since $k=1/Q_2=r_2/L_2\omega$, then if this value of k be substituted for the k in Equation (7), it will be found that

$$L_1=r_3/\omega+r_2/\omega=2r_2/\omega \quad (9)$$

From the equations given hereinabove, it will be apparent that the constants of a wave filter for the suppression of a particular frequency may be readily determined, upon the assumption, however, that the inductances of windings L_1 and L_2 and the resistances in series therewith are equal. A somewhat different relationship will exist when the inductances of windings L_1 and L_2 are unequal. Upon transposing the first and third terms of Equation (5), the following expression will result:

$$L_1=\frac{r_3r_2}{M\omega^2}+M \quad (10)$$

To produce a minimum of inductance in winding L_1 with respect to the mutual inductance M , it is necessary to differentiate Equation (10) with respect to M and equate the result to zero. Then

$$\frac{-r_3r_2}{M^2\omega^2}+1=0 \quad (10a)$$

or

$$M=\frac{1}{\omega}\sqrt{r_3r_2} \quad (10b)$$

and since $r_3\omega=L_3/Q_3$, and $r_2/\omega=L_2/Q_2$, it will be clear from Expression (10b) that

$$M=\sqrt{\frac{L_3L_2}{Q_2Q_3}} \quad (10c)$$

and it will be clear from Expression (6b) that

$$k=1/\sqrt{Q_2Q_3} \quad (10d)$$

Substituting in Equation (10) the value of M determined by Expression (10b), then

$$L_1=\frac{2}{\omega}\sqrt{r_3r_2} \quad (11)$$

It will now be clear that the constants of the filter for the suppression of a particular frequency may be easily determined even when the inductances of windings L_2 and L_3 are unequal. In this case, the ratio of reactance to resistance, the ratio of the inductance of winding L_2 to that of winding L_3 , and the

ratio of the resistances in series with these inductances may be set at any desired values.

In case a filter is required which shall be suitable for the elimination of several frequencies, or of several bands of frequencies, a number of shunt elements composed of inductance and capacity such as those designated L_2 and C_2 , and L_3 and C_3 , respectively, may be employed in association with a common series coil or reactor such as is designated L_1 . Manifestly, this may be done because the shunt elements are composed of series resonant circuits in parallel relationship so arranged that the resonance adjustment of one will not be effected by the presence of the other shunt branches.

Fig. 2 shows two of a plurality of sections which may be interposed between the input circuit A and the output circuit B, these sections including series reactive elements L_1 and L'_1 , respectively. Such an arrangement is highly desirable for the elimination of two or more particular frequencies, or of two or more narrow bands of frequencies, and it will be clearly understood that other sections similar to those shown may be connected between circuits A and B within the scope of the invention.

In Fig. 2, the circuit including winding L_3 and condenser C_3 shunts the input circuit A. As in Fig. 1 of the drawings, a circuit including winding L_2 and condenser C_2 is coupled thereto. The circuits including winding L_4 and condenser C_4 , winding L_5 and condenser C_5 , may be similar in all respects to the circuits including winding L_2 and condenser C_2 , and winding L_3 and condenser C_3 , respectively. The circuit including winding L_1 and condenser C_1 is tuned to be resonant at a different frequency, or at a different band of frequencies, from the frequency or band of frequencies to which the circuit including winding L_2 and condenser C_2 is tuned. The two sections shown, which include the series reactors L_1 and L'_1 , respectively, are associated with circuits which need not have identical or substantially equal components of reactance and resistance. It will be clearly understood that any number of other tuned circuits, similar to those shown, may be employed in connection with each section, these circuits being suitably coupled together as shown and employed for the purpose of suppressing other particular frequencies or bands of frequencies.

It will be apparent that the elements of the circuits associated with reactor L'_1 are designated by primed reference characters and that these may be similar to those associated with reactor L_1 . It will also be apparent that each pair of series circuits may be adjusted in their coupling to produce equality of the voltages of a particular frequency, or band of frequencies, to be suppressed and that phase adjustment may be produced by variations in

the magnitude of the inductance or of the capacity, or both, included therein.

Fig. 3 of the drawings shows a curve characteristic of the network shown herein, this curve exhibiting the relationship between frequency and the ratio of the voltage at the output circuit B to that at the input circuit A. This curve has been constructed from the constants determined by a network which may suppress current having a frequency such, for example, as 720 cycles.

The curve shows that the voltage ratio is zero at the particular frequency f to be eliminated, and that the voltage ratio is substantially negligible at a band or range of frequencies about point f . However, the curve shows a high voltage ratio at a frequency substantially different from and lower than frequency f , and yet since the voltage ratio is greatly different from a negligible amount, this condition seems insignificant.

While this invention has been pointed out in certain particular arrangements, merely for the purpose of illustration, it will be understood that the general principles of the invention may be applied to other and widely varied organization without departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. A filter comprising a series circuit having an element of inductance and two shunt circuits each including an element of inductance and an element of capacitance, the inductances of said shunt circuits being mutually reactive, the elements of inductance and capacitance of one of said shunt circuits being tuned to a frequency or to a narrow band of frequencies, to be substantially eliminated, said filter eliminating current of said frequency or currents within said narrow band of frequencies impressed thereon.

2. A filter comprising an inductance as a series element and first and second series resonant circuits as shunt elements, the inductances of said series resonant circuits being mutually reactive, the first of said series resonant circuits being tuned to the frequency of the current to be eliminated, and means associated with the second of said series resonant circuits whereby there may be produced in the first of said series resonant circuits a voltage at the frequency of the current to be eliminated equal and opposite to the voltage produced by said first series resonant circuit.

3. A filter comprising a plurality of recurrent sections, each section including a reactor, a first series circuit connected in shunt with the output terminals of said filter and comprising inductance and capacitance, a second series resonant circuit connected in shunt with the input terminals of the filter also comprising inductance and capacitance, the reactor interconnecting the said first and

second series circuits, the first series circuit being tuned to the frequency of the current or to the frequencies of the currents within the narrow band to be substantially suppressed, and means whereby the second series circuit may produce in the first series circuit a voltage at the current of said frequency or at the currents within the narrow band of frequencies to be substantially suppressed equal and opposite to the corresponding voltage or voltages produced by the first series circuit.

4. A filter interconnecting an input circuit and an output circuit, comprising a series inductive element, two mutually reactive shunt elements which shunt the input and output circuits respectively, and means for rendering the element in shunt with the output circuit resonant at the frequency of the current to be eliminated so that the voltage at the frequency to be eliminated impressed thereacross may be brought to a predetermined value, said elements being so related that the voltage at the frequency to be eliminated which becomes impressed across the element in shunt with the output circuit will be balanced out by another voltage produced by said elements which is equal in magnitude and opposite in phase to that produced across the element in shunt with the output circuit.

5. A filter comprising, in combination, an input circuit, an output circuit, a winding of low inductance serially connected between said input and said output circuits, a first series circuit including inductance and capacity in shunt with said input circuit, a second series circuit including inductance and capacity in shunt with said output circuit and resonant at the frequency of the current to be suppressed, and means whereby said first series circuit may produce in said second series circuit a voltage at the frequency of the current to be suppressed substantially equal to that produced by said second series circuit at the same frequency, both of said series circuits being so arranged that the relative phases of the voltages of the resonant frequency impressed upon said second series circuit may be brought to opposition.

6. The combination with an input circuit and an output circuit of a filtering arrangement comprising a reactor serially placed between said input and output circuits, four series circuits each having an inductive reactance and a capacitive reactance, two of said series circuits shunting the input circuit, the other two of said series circuits shunting the output circuit, each series circuit shunting the output circuit being resonant at the frequency of one of the currents to be suppressed, and means including said series circuits shunting said input circuit to establish in the two series circuits shunting said output circuit voltages at the frequencies of the currents to be suppressed substantially equal

and opposite to those voltages produced at the same frequencies respectively by the series circuits shunting the output circuit.

5 7. A filter interconnecting an input circuit and an output circuit, comprising a reactor in series between said input and output circuits, a series resonant circuit in shunt with said output circuit freely by-passing current to be suppressed, a series circuit in shunt
10 with said input circuit not resonant with the series circuit shunting said output circuit, and means to couple said series circuits so that the voltage of the current intended for suppression by-passed by the series circuit
15 shunting the output circuit may be neutralized by a voltage equal in magnitude and opposite in phase to the voltage of the current of the same frequency by-passed by the series circuit shunting the output circuit.

20 In testimony whereof, I have signed my name to this specification this 26th day of May, 1928.

RALPH G. McCURDY.

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